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Mine Illumination

Proceedings: Second International Mine Lighting Conference of the International Commission on Illumination (CIE)

Compiled by K. L. Whitehead and W. H. Lewis

UNITED STATES DEPARTMENT OF THE INTERIOR

I 28.27:

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March 3 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
James G. Watt, Secretary

BUREAU OF MINES
Robert C. Horton, Director

This publication has been cataloged as follows:

International Mine Lighting Conference of the International Commission on Illumination (CIE) (2nd : 1981 : Beckley, W. Va.).
Mine illumination.

(Information circular ; 8886)

Includes bibliographical references.

Supt. of Docs. no.: I 28.27:8886.

1. Mine lighting–Congresses. I. Whitehead, K. L. (Kenneth L.). II. Lewis, W. H. (William H.). III. International Commission on Illumination. IV. Title. V. Series: Information circular (United States. Bureau of Mines) ; 8886.

TN295.U4 [TN301] 622s [622'.47] 82-600187 AACR2

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MINE ILLUMINATION

Proceedings: Second International Mine Lighting Conference of the International Commission on Illumination (CIE)

Compiled by K. L. Whitehead[1] and W. H. Lewis[2]

ABSTRACT

The U.S. Bureau of Mines, Department of Labor, and United States National Committee of the CIE hosted the TC4.10 Mine Lighting Committee Meeting and Second International CIE Mine Lighting conference at the MSHA Academy in Beckley, WV from October 12-16, 1981. This was the first time the meeting and conference had been held in the United States.

The TC4.10 Mine Lighting Committee, chaired by Dr. Adam Peretiatkowicz of Poland, was attended by 15 committee members and six guests representing eight countries. Discussion during the meeting covered mine lighting instrumentation, open cast (surface mine) lighting, and lighting sources. The committee also reviewed a draft of proposed lighting terminology and suggested changes to make the definitions more acceptable to representatives of the nations present.

The mine-lighting conference featured 20 papers presented by 18 speakers representing six countries. The papers covered all phases of mine lighting, including research, hardware development and application, personnel acceptance, and requirements for system maintenance. The conference attracted 126 attendees and also included displays by eight lighting hardware manufacturers and four mining machine manufacturers. Papers from the conference are being published by the Government Printing Office, with copies presented to the conference attendees. Copies will be available to others interested through the NTIS. During the course of the TC4.10 meetings and conference, committee members toured three mining equipment assembly plants, and six of the foreign representatives visited a longwall installation in an underground mine.

Planning and administrative services for the meeting and conference were handled by Bituminous Coal Research, Inc., under USBM Contract H0318038.

---

[1] Supervising Engineer, Bituminous Coal Research, Inc., Monroeville, PA

[2] Group Supervisor, Mine Illumination Research, U.S. Bureau of Mines, Pittsburgh Research Center, Pittsburgh, PA

TC4.10 MINE LIGHTING COMMITTEE MEETING

The TC4.10 Mine Lighting Committee was formed in 1975 at Session XVIII of the CIE in London, England. The committee's main tasks are to prepare international recommendations for underground mine lighting, coordinate ideas on the basic parameters of mine lighting, and make recommendations for lighting particular areas such as the coal face.

To help achieve these goals, three subcommittees have been formed as follows:

SC4.10A - Mine Lighting Measurements
Chairman - Dr.-Ing. Bruno Weis

SC4.10B - Open Cast Lighting
Chairman - Kenneth Whitehead

SC4.10C - Mine Light Sources
Chairman - Don Trotter

Members of the TC4.10 International Committee and of the American Mine Lighting Committee are included as Appendix A.

The agenda for the committee meeting follows. Minutes of the meeting are being prepared by Dr. Peretiatkowicz, Committee Chairman, for distribution to committee members. Copies can be obtained by contacting the chairman or a committee member. The CIE documents reviewed at the meeting were:

1. Minutes of the TC4.10 Meeting at Kokotek, April 21-22, 1980
2. Mine Lighting Terminology Report - 5th Draft
3. International Recommendation for Underground Mine Lighting - 5th Draft

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TC4.10 COMMITTEE MEETING AGENDA

I. TECHNICAL COMMITTEE TC4.10 Held October 12-13, 1981

Dr. Adam Peretiatkowicz, Chairman

1. Opening of the meeting and welcome by the Chairman
2. Appointment of the Secretary and Reporters
3. Acceptance of the meeting program
4. The Chairman's brief report on the TC4.10 activities since Kyoto Session. Minutes of the meeting in Kokotek and report on the Symposium "100 years of Electrical Illumination in Silesian Collieries"
5. Discussion on the TC4.10 activity and approval of the Chairman's proposition

II. Subcommittee SC4.10A, "Mine Lighting Measurements"

Dr.-Ing. Bruno Weis, Chairman

1. Presentation of the working program
2. Dr. Weis, Germany, propositions
3. Discussion and approval of the working program in the years 1981 to 1983

III. Subcommittee SC4.10B, "Open Cast Lighting"

1. Draft of the working program
2. Discussion
3. Appointment of the Subcommittee Chairman*
4. Approval of the working program

IV. Subcommittee SC4.10C, "Mine Light Sources"

Prof. Donald Trotter, Chairman

1. Presentation of the SC4.10C activity since April 1980
2. Discussion
3. Discussion and approval of the Chairman's working program for the coming years

V. Technical Committee TC4.10

Dr. Adam Peretiatkowicz, Chairman

1. Presentation of the 5th draft of the CIE Recommendation for Underground Mine Lighting
2. Discussion
3. Presentation and approval of the 5th draft of the TC4.10 terminology and discussion on further works
4. Information of the CIE reorganization
5. Approval of the Subcommittees' working programs presented by the SC Chairmen
6. Future Committee meetings in 1982 and 1983
7. Other business
8. Closing the meeting

---

*Mr. Kenneth L. Whitehead, Bituminous Coal Research, Inc., was appointed Chairman of the SC4.10B Committee.

SECOND INTERNATIONAL MINE LIGHTING CONFERENCE

The Second International Mine Lighting Conference, held in conjunction with the TC4.10 Mine Lighting Committee Meeting, was a part of the CIE program of international cooperation and exchange of information among member countries on all matters relating to the art and science of lighting. Membership consists of 30 countries, each having a National Committee of individual members who devote their time and talent to the objectives of the organization. In addition, individuals from 10 other countries have Associate Member status. Members of the United States National CIE Committee are listed in Appendix B.

The objectives of the CIE are:

1. to provide an international forum for all matters relating to the art and science of lighting;
2. to promote by all appropriate means the study of such matters;
3. to provide for the interchange of lighting information among the different countries;
4. to prepare and publish international agreements in the field of lighting.

The work of the CIE is carried on by 26 Technical Committees, each of which is assigned to a member country. These cover subjects ranging from those which involve basic and fundamental matters to all types of lighting applications. The reports and guides developed by these international committees are possible only through an organization such as the CIE and are accepted throughout the world.

A Plenary Session is held every four years at which the work of the committees is reviewed and reported, and plans are made for the future. The CIE is recognized as representing the authority on all aspects of light and lighting. As such it occupies an important position among international organizations.

All but one of the papers included in this report were presented at the Second International CIE Mine Lighting Conference. That paper, "Definition of Illumination Requirements for Underground Metal and Nonmetal Mines," was submitted only for publication in the proceedings. The purpose of the conference was to provide a program of both technical interest and practical value to attendees associated with underground, strip, and metal-nonmetal mining.

Speakers invited to present papers were selected from individuals involved in management and research activities related to mine lighting, as well as those who have effectively applied lighting technology to the mining industry. The conference planning committee felt that the publication of the experience of these individuals would make a significant contribution to the data base concerning the effect of mine lighting on improved safety, environmental control, and production.

In addition to the speakers, manufacturers of mine-lighting hardware and of mining equipment displayed their products to provide attendees with information on currently available hardware. The manufacturers which participated in the conference are listed in Table 1 and illustrations of the display areas are shown in Figures 1 through 4.

CONFERENCE PAPERS

Included in this section are the keynote address delivered by Dr. S. K. Guth, Past President of CIE; conference papers; and biographical sketches of the speakers presenting them. The speakers represent expertise in all phases of mine lighting and reflect international experience in the development and application of mine lighting technology.

TABLE 1. - Manufacturers participating in the Second International Mine Lighting Conference

Lighting Equipment Manufacturers

McJunkin Corporation
PO Box 513
Charleston, West Virginia 25322

Mine Safety Appliances
600 Penn Center Boulevard
Pittsburgh, PA 15235

National Mine Service
U.S. Route 22 & 30 West
Old Steubenville Pike
Oakdale, PA 15071

Ocenco, Inc.
PO Box 8
101 Industrial Park
Blairsville, PA 15717

Mining Controls, Inc.
PO Box 1141
Beckley, West Virginia 25801

Permalux Lighting Products, Inc.
Box 351
Maple Shade, New Jersey 08052

Safety Lamp of Houston, Inc.
15550 West Hardy Road
Houston, Texas 77060

Siemens Corporation
186 Wood Avenue South
Iselin, New Jersey 08830

Mining Equipment Manufacturers

Fairchild Inc.
PO Box 890
Beckley, West Virginia 25801

FMC Corporation
Mining Equipment Division
Tenth and Beltline
Fairmont, West Virginia 26554

Lee-Norse Company
401 Ragland Road
Beckley, West Virginia 25801

Long-Airdox
PO Box 331
Oak Hill, West Virginia 25901

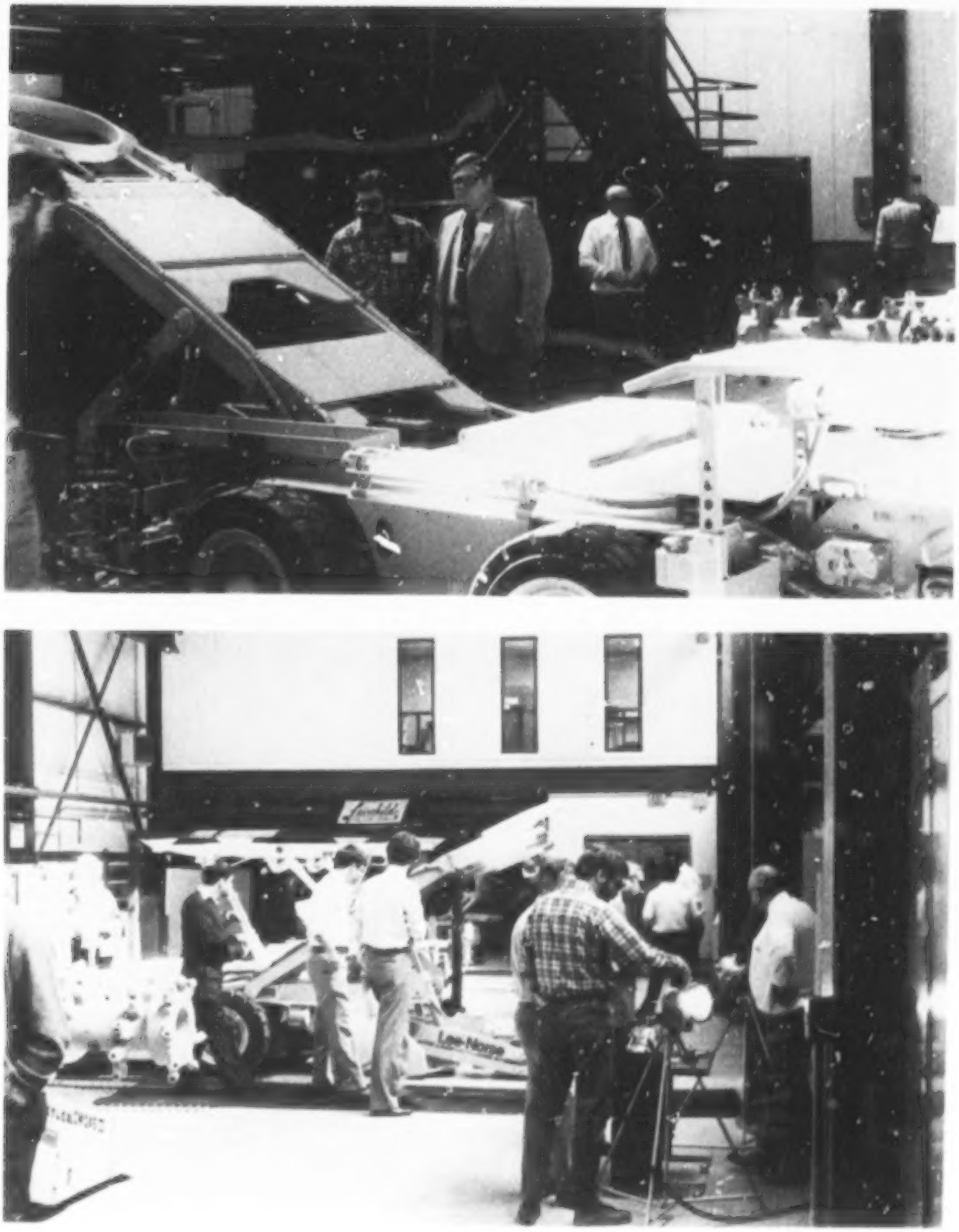

FIGURE 1. - Mining equipment display area.

PERMALUX
LIGHTING
PRODUCTS
INC.

FIGURE 2. - Lighting hardware manufacturers' display area.

ocenco
INCORPORATED
The
Mine Lighting
Experts
Leadership
in safe
Underground Lighting
• Low Voltage
• Low Wattage
• Low Glare
• Low Coal Design
McJunkin
CORPORATION

FIGURE 3. - Lighting hardware manufacturers' display area.

FIGURE 4. - Lighting hardware manufacturers' display area.

KEYNOTE ADDRESS: Mine Lighting and the CIE

TITLE OF PAPER: Discomfort Glare Sensitivity
of Underground Mine Personnel

AUTHOR: Dr. Sylvester K. Guth (Retired)
Lamp Division of General Electric

Dr. Guth received a B.S. Degree and a Professional Degree in Electrical Engineering from the University of Wisconsin, and Doctor of Ocular Science Degree by the Northern Illinois College of Optometry.

He has been active in the work of the Illuminating Engineering Society (IES) as chairman of the Society's Committee on Recommendations for Quantity and Quality of Illumination, and its Nomenclature Committee. He also has served on the Papers, Illumination Performance Recommendation, Color and Illumination, and Research Committees, and for many years was the Society's official representative to the American Association for the Advancement of Science. He has served for many years on the Technical Advisory Committee for Light and Vision of the Illuminating Research Institute. Dr. Guth was made a Fellow of the IES in recognition of his outstanding technical contributions.

In 1967, Dr. Guth was awarded the IES Gold Medal, the Illuminating Engineering Society's highest honor "in recognition of a lifetime devoted to research on light and vision, and especially for his pioneer work in the psychological evaluation of glare sensation, with its relation to visual comfort."

Dr. Guth was elected a Fellow of the American Academy of Optometry and of the American Association for the Advancement of Science, and is a member of the Optical Society of America, the Inter-Society Color Council, the Illuminating Engineering Society (London), the National Research Council Committee on Vision, and the American Society for Photobiology.

Dr. Guth joined the Lamp Division of G.E., Nela Park, in 1930, and was put in charge of lighting research activities in 1950.

From 1956 to 1968, he was manager of the Radiant Energy Effects Laboratory, responsible for researches on the effects of radiant energy on man, animals, and plants. On January 1, 1969, he was appointed Manager, Applied Research, and was responsible for researches in vision, visibility, visual and human performance, visual comfort, color and physiological effects of radiant energy (UV, visible, and IR).

During his career with General Electric, Dr. Guth performed or directed most of the investigations at Nela Park in the fields of light, vision, and seeing. He developed many criteria and techniques used in evaluating visibility, contrast sensitivity, ease of seeing, glare and quality of lighting. He also devised demonstration materials and equipment to illustrate the effectiveness of illumination on these factors. His work on discomfort glare has been recognized all over the world, and is the basis of the Visual Comfort Probability (VCP) method adopted in the Illuminating Engineering Society of North America.

He retired in 1974.

MINE LIGHTING AND THE CIE

by

Sylvester K. Guth[1]

ABSTRACT

Mining has been and continues to be an important industry in many countries. It was recognized as an area involving unique snd special lighting problems in 1931 when the CIE established Study Committee 29. Since then, except for one brief period, mine lighting has been among its more active committees. Currently, 19 countries are contributing to the work of CIE Committee TC-4.10. The present Conference--the second of its type--is an excellent example of the importance attached to mine lighting. It is expected that the papers and the discussions will provide considerable useful information for the Committee.

TEXT

As a long-time active participant in the technical and administrative affairs of the International Commission on Illumination, I was delighted to be invited to be the keynote speaker at this Second International Conference on Mine Lighting. I am particularly pleased with the decision to hold the Conference in the United States. In looking back over the years, I believe this is only one of two or three international meetings cosponsored by a CIE Committee that has been held in this country. For a long time the CIE Board of Administration and the Action Committee have been encouraging the Technical Committees to sponsor meetings and synposia and to seriously consider holding them outside of Europe. Doing so emphasizes the world-wide internationality of the CIE and also permits the participation of many people who otherwise would not be able to contribute to its work. Thus, speaking for the CIE Administration, I welcome you to this Conference.

On behalf of its President, Mr. Franc Grum, I also bring you greetings from the United States National Committee of the CIE. One of our hopes is that the success of this Conference will demonstrate the effectiveness of holding such meetings over here and to stimulate others to do the same.

My task, as the keynote speaker, is to set the stage for this Conference. To do this, it seems appropriate to review very briefly the mine lighting activity in the CIE, with special emphasis on the past several quadrennia.

---

[1] Past President, International Commission on Illumination, South Euclid, Ohio.

Mining is an important industry in many countries and has been for countless years. It was recognized as an area involving unique and special lighting problems in 1931 when the CIE established Study Committee 29. For the next 34 years mine lighting was among the more active of the Secretariat Committees. At each Plenary Session during this period, the reports on mine lighting problems and developments in various countries and the individual papers resulted in considerable discussion. The subjects dealt with included visibility, glare, measurement of illumination and luminance, lighting methods and regulations. While no definitive technical reports were issued by the Committee, the information presented at the Plenary Sessions provided the various countries with considerable useful material for developing improved codes and regulations.

Even though there appeared to be a number of problems that needed working on, the proposal made at the Vienna Session in 1963 to convert mine lighting from a Secretariat to an Expert committee was not approved by the Action Committee. The reasons for this were the decline in coal mining in many countries and the apparent difficulty of the Chairman to obtain active cooperation from the National Committees. Consequently, in 1967 the Committee was discontinued.

Despite the fact that a separate group working on mine lighting no longer existed, there was a feeling that it should not be completely eliminated from the CIE technical activities. Therefore, Committee TC-4.1 on Interior Lighting was asked to look into the matter. If there appeared to be sufficient interest and full cooperation could be obtained from National Committees, a panel would be organized within that Committee to look after mine lighting.

At about this same time the Polish National Committee on Illumination submitted a proposal to establish a Study Group which would have the task of determining if there was sufficient interest to reactivate the committee on mine lighting. This proposal, which paralleled one made by TC-4.1, was approved by the Action Committee. Accordingly, a Study Group was set up under the chairmanship of Dr. Peretiatkowicz with the assignment of developing and proposing Terms of Reference and a Working Program for a Technical Committee. This turnabout indicated that the CIE Administration was responsive to the needs and desires of the National Committees and was willing to change its previous position.

The new Study Group was very active and obtained the support of many countries. Much of the new interest in coal mining, obviously, was the result of the energy crisis which began to be felt throughout the world in 1973. Because of the strong response by National Committees, the Action Committee at the 1975 London Session included TC-4.10, Mine Lighting, on the roster of currently active CIE Technical Committees.

Under the chairmanship of Dr. Peretiatkowicz the Committee has made considerable progress since its reactivation. This was evidenced by the 1978

International Conference in Poland and the well-attended meetings at the 1979 Kyoto Session. I should mention that the CIE Action Committee thoroughly reviews the work of all the Technical Committees at least once a year. The reports on TC-4.10, which have been summarized in the CIE Bulletin, are good indicators that positive progress is being made.

According to the latest CIE Roster, 19 countries are represented on TC-4.10. Its Terms of Reference are: "To study the fundamental aspects of the lighting of underground and open-cast mining." The Working Program now includes:

1. To analyze and prepare recommendations for the lighting of open-cast mines.
2. The application of photometric measurements in mines.
3. To investigate and make recommendations on personal lamps.
4. To investigate the requirements for underground mine lighting.
5. Terminology.

This ambitious but attainable program is in the hands of three subcommittees.

This brings me to the present Conference which illustrates the current interest in and the importance attached to mine lighting. According to preliminary information, we have representatives from at least eight countries as compared to five at the first Conference. The attendance certainly indicates the seriousness with which the many lighting and visual problems in mines are taken.

While I have been deeply involved with lighting and vision research for more than half a century, my first real contact with mine lighting did not come until about two years ago. Of course, many of my research results on visibility and glare were pertinent to conditions in mines, but none of the investigations were aimed specifically at this lighting application.

Even from my limited experience, it is evident that the lighting of mines involves many unique problems. Developments of machines and automated procedures have eliminated some of the back-breaking work by pick and shovel. However, the machines are operated by people who must be able to see. About everything involves movement and thus the tasks are dynamic; far different than a man standing or sitting at a machine in a factory. The mine worker must be able to see in order to accomplish his task and, more important, to be safe. Indeed, safety is the key word in mining.

The machine operator and other workers in a mine need to be able to orient themselves in a difficult visual environment. Under the most adverse conditions, illumination must be provided on all mine surfaces and machines, ideally without glare. General lighting, as in a factory, is out of the question. Mobility demands lighting equipment mounted on machines and workers. Moreover, such equipment must be durable to withstand the rigors of physical abuse and without introducing hazards in what may become a potentially dangerous situation.

A review of the papers to be presented at this Conference indicates that just about every aspect of mine lighting will be covered. I am sure that they and the discussions which are sure to follow will be interesting and stimulating as well as providing considerable useful information for the members of CIE Committee TC-4.10. I, too, expect to learn a great deal.

In closing this presentation, I should say a word or two about this meeting place. The National Mine Health and Safety Academy is a unique institution and I cannot think of a more appropriate location for the Conference. It is dedicated to improving the health and safety conditions in U.S. mines. As such, its objectives are identical to those of the CIE. I am sure that when you leave this Conference you will do so with a feeling that these two days have been most worthwhile.

DISCOMFORT GLARE SENSITIVITY OF UNDERGROUND MINE PERSONNEL

by

Sylvester K. Guth[1]

ABSTRACT

A large group of underground miners adjusted the luminance of a glare source in a standardized visual environment to produce a sensation at the borderline between comfort and discomfort (BCD). The data, on the average, indicate that the miners are less sensitive to glare than those whose data were used for developing the discomfort glare rating system for interior lighting.

INTRODUCTION

Extensive investigations (1) have resulted in the development of a discomfort glare evaluation procedure for interior lighting (2). Those investigations, conducted over a period of about 20 years, involved a total of more than 200 observers who made subjective evaluations of a wide variety of lighting conditions and systems corresponding to those encountered in offices, schools, and industry. A significant result of employing the large number of observers was the development of a Visual Comfort Probability (VCP) basis for rating lighting systems. This permitted expressing discomfort glare evaluations in terms of the percent of observers who would be expected to judge a lighted environment as being acceptable. The VCP scale was derived from the subjective judgments and thus represents the relative sensitivity to discomfort glare of that population sample. Furthermore, the application of the VCP procedure indicated that it was consistent with the experience. In other words, computed ratings showed that the observers as a group and in terms of glare sensitivity were representative of those working in offices, schools, and industry.

Since the environment in mines is considerably different from typical lighted environments, a number of questions arise if one wants to apply the VCP procedure to mine lighting. An important and basic one concerns the sensitivity of mine personnel to discomfort glare. If a large group of miners exhibited the same sensitivity as the interior lighting population and also gave the same type of frequency distribution, the VCP procedure could be expected to be applicable to the mine environment. Any difference, especially with respect to glare sensitivity, will require some modification in the VCP procedure.

---

[1] Consultant, South Euclid, Ohio.

This paper is a brief summary report on that part of a more extensive investigation dealing with the evaluation of glare in coal mines. It is concerned with the sensitivity of underground miners to glare. The objective is to determine if those who spend considerable time in coal mines are more or less sensitive to discomfort glare than the population used for developing the Visual Comfort Probability procedure applicable to interior lighting.

EXPERIMENTAL CONDITIONS

Discomfort Glare Calibrating Device

The environment in which the glare source was evaluated was a cubicle used in conjunction with the Discomfort Glare Evaluator (3). The cubicle was designed to approximate the large sphere used in the basic BCD investigations (4). It was 100 cm deep, 80 cm high, and 60 cm wide (40 x 32 x 24 inches). A head- and chinrest were positioned at the front opening so as to locate the eyes of the observer even with the front panel. The test source was viewed through a circular aperture on the horizontal line of sight in the rear wall of the cubicle. The size of the aperture subtended a solid angle of 0.0011 steradian, the same as that used in the original basic discomfort glare investigations.

The luminous element of the Discomfort Glare Evaluator was reflected toward the observer's eyes by a diagonal mirror located outside the rear of the cubicle. The luminance of the source, which was under the control of the observer, was continually variable from 0 to 40 000 cd/m^2 (0 to 12 000 fL).

The interior of the cubicle could be illuminated to provide field luminances of 3.4, 34, and 340 cd/m^2 (0.1, 1.0, and 10 fL). The arrangement for providing the source luminance, being external, did not measurably affect the internal luminance of the cubicle.

Observers

A total of 115 observers participated in the investigation. However, incomplete or very erratic data were obtained from 14 observers and their results have been excluded from the analyses.

Miners came in for testing either just before going on a work-shift or as they came off a shift. While workers from all the shifts were represented, it was not possible to obtain a complete balance.

Procedure

Each observer adjusted the luminance of the test source until he judged it to produce a sensation of the borderline between comfort and discomfort (BCD sensation). The source, which was viewed directly, was exposed for 1 second intervals separated by 1 second off periods. The 1-second momentary procedure was developed for the original discomfort glare investigations (4) and found to be long enough for the observer to receive the full impact of glare but sufficiently short so that the source luminance did not significantly affect adaptation. This latter point is particularly important when the field luminance is low.

Each observer made a series of at least five BCD judgments for each field luminance. In some cases, a repeat set of observations was made with the 34 cd/m^2 (1 fL). About one-fourth of them made observations before and after the same shift, but on different days.

RESULTS AND ANALYSES

The geometric mean luminances judged by the 101 observers to produce the BCD sensation are given in the table. Also included are the corresponding BCD luminances computed from the Guth formula (1). The latter are from what might be called a typical office worker population involving more than 200 observers.

Field luminance	3.4 (0.1)	34 (1)	343 (10)
BCD - miners	1216 (355)	2326 (679)	4296 (1259)
BCD - office workers	442 (129)	1216 (355)	3351 (978)

It is evident that the miners selected considerably higher BCD luminances than the office population. However, the differences are not the same as the three field luminances, the ratios being 2.75, 1.91, and 1.28.

The relationships in the table can be represented by the following equations:

$$\text{Miners} \qquad L = 2326F^{0.28} \tag{1}$$

$$\text{Office workers} \qquad L = 1216F^{0.44} \tag{2}$$

where L is the BCD luminance of the source and F is the field luminance, both expressed in cd/m^2.

The differences in the exponents of F was surprising. All of our previous BCD investigations have resulted in an exponent of 0.44. One of these investigations (5), involving an evaluation of discomfort glare from sodium, mercury, and filament lighting for roadways, included the same field luminances used in the present one. Similarly, work reported by Putnam and Faucett (6) at low luminance levels also indicated the exponent to be about 0.44. Other investigators (7) have reported the exponent to be between 0.5 and 0.6.

At present, no reason can be given for the lower exponent obtained from the BCD data of the miners. The experimental procedure is not suspect because it was identical to that employed in many previous researches. The Discomfort Glare Evaluator is one that was used in other investigations.

A preliminary analysis of the average BCD values obtained by the miners shows that the distributions are somewhat skewed. The skewedness appears to be approximately the same for the three field luminances. This analysis also emphasizes the relatively large range of BCD luminances for the mining population. Relative BCD luminances for the more and less sensitive groups of observers ranged from 8 to 634, or a ratio of 80 to 1. This compares with a range of 25 to 550 and a ratio of 22 to 1 in relative BCD luminance obtained with the office workers. The selection of somewhat lower BCD luminances by the miners is one reason for the skewed relationship.

CONCLUSIONS

The data obtained by the underground miners are considered to be quite good, considering that none of them had ever participated in this type of investigation. In most cases their results were internally consistent. Some BCD judgments resulted in rather low or high luminances, indicating that those observers probably did not fully understand the instructions.

The higher BCD judgments of the miners as compared with the office workers does not seem to key in with their environmental working conditions. That is, because they spend their working hours in a dark environment, one would expect them to be more sensitive to glare. However, in a typical mine many miners often are subjected to rather high degrees of glare, especially from the lighting equipment on machines. Such exposure to glare would be expected to make them less sensitive and thus select higher BCD luminances.

The results of this investigation, in terms of preliminary analyses of the data, lead to the conclusion that, on the average, the mining population is less sensitive to discomfort glare than a non-mining population. Apparently, the dark working environment does not adversely affect glare judgments. However, since a small but significant percent of the miners are quite sensitive to glare, it is misleading to consider only the average BCD value. When establishing permissible source luminances in mines it is necessary to take into account the more sensitive individuals.

Further analyses of the data need to be made to determine if such effects as age, work shift, number of years as an underground miner, etc., have any influence on judgments of discomfort glare.

The author expresses appreciation to P. D. Lindahl who did the BCD testing of the miners for the excellent manner in which he carried on the investigation.

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TITLES OF PAPERS: Problems of Electric Mine
Lighting in the Work of CIE

Mine Underground Illumination
in Poland

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MINE UNDERGROUND ILLUMINATION IN POLAND

by

Adam Peretiatkowicz[1]

ABSTRACT

As a main task of this paper, the author was asked to acquaint American participants of the 2nd International Mine Lighting Conference with illumination technics used in Polish underground mines.

In the introduction is a short description of the characteristics of main branches of the Polish mining industry; i.e., the hard coal mining, the copper ore and zinc-lead ore mining as well as the rock-salt(halite) mining industry.

Discussion on several illumination systems, used in various types of headings in Polish underground mines, have been limited to short characteristics of the solutions applied there. Not dwelling upon a general illumination system of fixed headings--as chambers, galleries, etc.,--greater attention has been called to the problem of general illumination systems applied within preparatory faces (as sinked shafts, end gates, etc.) as well as working faces (longwalls and sloping faces). In this chapter both general illumination systems--supplied directly from the mains--and those affected by means of self-propelled mining machines have been discussed.

In the next chapters, some of the battery lamps used in Poland have been presented, among them end lamp, portable lamp for general illumination of a place of rescue action, and portable lamp for repair gangs.

INTRODUCTION

Mining is one of the basic Polish industries. The following amounts of minerals are mined by means of underground methods (according to data of 1978):

- hard coal - 195 millions tons/year
- copper ores - 27 millions tons/year
- zinc - lead ores - 5,5 millions tons/year
- rock salt (halite) - 1,4 millions tons/year

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In the same year the following amounts of other minerals have been mined in open pit plants:

- brown coal (lignite) - 44,1 millions tons/year
- sulphur - 4,8 millions tons/year (partly using the Frash's method)
- others, as limestones, stones, etc.

Short characterization of the mining branches based on the underground exploitation methods is as follows:

Hard Coal Mining

Hard coal mining is of dominating importance in Poland--from the point of view of both annual production and employment. At the moment two hard coal basins are being operated in Poland:

- Upper Silesia Basin, giving approximately 95% of the total productivity (from deposits located in the area of approximately 600 sq. km).

- Lower Silesia Basin, giving approximately 3% of the total productivity (mainly coking coals).

Besides these two basins, the third one is being prepared now for exploitation, with its first mine under construction. The newest basin is located in the southeastern part of the country, close to Lublin city.

In the Upper Silesia Basin the coal deposits occur almost horizontally, with their average thickness around 2.1 m; however, the maximum thickness reaches up to 21 m--in the 510 m ledge. The coal ledges occur in layers and in some places happen also to be separated by zinc--lead ore ledges.

Total thickness of the hard coal ledges reaches 62 meters in the eastern part of the coal basin and up to 140 meters in its western part. Such an occurrence of the coal ledges causes that, in particular mines, coal is mixed simultaneously from ledges on different depths. Presently the mines are operated on depths between 200 and 1000 meters; however, 60% of the mined coal comes from the ledges occurring down to 500 meters.

The ledges under operation have a minimum thickness of 0.5 m while thicknesses are exploited layer by layer, using hydraulic filling. The most popular exploitation method is longwall (over 85% of the total productivity), based on the use of self-movable, mechanized mining and continuous miners.

There are usually several longwalls within an exploitation field. having several hundred meters each. The coal mined by means of the continuous miners is loaded onto wall-type push-plate conveyors and, subsequently, is hauled by means of belt conveyors up to the loading station. Within the station, coal is reloaded into hauling cars of 5 tons capacity and taken to the pit bottom. Skip hoists (15-30 tons) are generally used to draw the coal out to the mine surface.

Copper Ore Mining

The Polish Copper Basin, located in the Lubin-Glogow-Legnica area, has reached its production level placing Poland among the six world leading copper producers.

The Polish copper ore mines operate on ledges having thickness of 4 to 7 meters, occurring on the depths between 600 and 850 meters. Good roof conditions enabled introduction of the chamber-pillar exploitation system and use of self-propelled mining machines both in face areas and directly in their vicinities. In the face areas, self-propelled drill trucks, roof bolting machines, and loaders are in a general use, supported by bulldozers and shuttle cars.

Zinc-Lead Ore Mining

At the moment, zinc-lead ores are mined mainly in the following two areas:

- the old basin in Bytom area, Upper Silesia, giving 11% of the total productivity, and
- the new basin in Olkusz area, giving 52% of the total productivity.

In the Polish zinc-lead ore mines, both longwall and pillar exploitation systems are operated. Material loading is mechanized and hauling cars (4.5 tons capacity) are used to take the material away from exploitation fields.

Rock-Salt Mining

Rock-salt has been exploited in Poland, in underground mines, since the Twelfth century. The oldest mines, being still under operation, are located in Wieliczka and Bochnia, southeast from Cracow.

Rock-salt is being mined, also, in underground mines located in the Klodawa-Inowroclaw area (central part of the country). Besides rock-salt, potassium salt deposits are also mined in northern Poland, at the Gdansk Bay.

MINE UNDERGROUND ILLUMINATION METHODS

After the short characterization of the Polish mining industry, I would like to present the illumination methods used in our mines. Information on this subject is arranged in four chapters in which illumination methods for headings, face areas, and preparation areas, as well as illumination equipment for the mining machines and individual personal and special battery illumination systems are shortly presented.

Fixed Heading Illumination

This group of headings includes all types of chambers, such as machine chamber, workshop chamber, store chamber, main pump station, small shaft hoisting machines, personnel transport stations, loading and unloading stations, as well as transportation galleries.

As far as the chambers are concerned, network illumination is used in all headings in which fixed workplaces exist as, for instance, workshop chambers, pump stations, machine rooms, etc.

On the other hand, the chambers in which casual work activities take place only, as store chambers, are also equipped with the network illumination but switched on only during personnel stay in the workplace.

Either discharge or incandescent light sources are used for chamber illumination systems. In case of a twenty-four hour lamp burning, discharge light sources and, for high chambers, mercury discharge lamps are preferred.

Pit bottoms and their areas are equipped, usually, with fixed electric lighting, for high rooms (over 3.5 meters) mercury discharge lamps, and fluorescent or incandescent lamps for lower rooms, according to a required illumination level. The same applies roughly to personnel transportation stations as well as to loading and unloading points.

Cross-cut and transportation gallery sectors, provided either for material hauling or pedestrian traffic, are equipped with fixed lighting systems, if traffic intensity proves it necessary under the respective Polish Standard (PN-73/G-02600). For illumination of such galleries, fluorescent lamps are preferred. Gangways provided for material transportation only, with pedestrian traffic prohibited, generally are not equipped with a network illumination, except cross-roads, junctions, and other places where hazardous conditions exist.

As it appears clearly from this presentation, on particular exploitation levels, network illumination exists in specific mine sectors, usually very distant from each other. Consequently, power supply for the lighting installations, grouped on small areas, is provided usually by means of small, 3-phase transformer illumination units of 1.6 up to 10 kVA and a range of an illumination network supplied from a unit does not exceed 250 meters. For gangway illumination, the 3-phase transformer units are generally spaced every 800 meters.

Preparation Heading Illumination

Discussing this subject, I would like to call your attention, gentlemen, to the problem of illumination of a sinked shaft bottom and, later on, to the problem of illumination of end gates, blast mined in both coal and stone.

Illumination of a Sinked Shaft Bottom

A movable working platform, suspended 15 up to 40 meters over the bottom of a sinked shaft, gives a base for electric power supply for the equipment used in the shaft sinking operation. The platform is utilized also for lighting the shaft tube underneath the platform as well as the shaft bottom. This lighting is arranged by means of two mercury-vapor reflector lamps of LFRF type, having power of 250 or 400 watts. These lamps are mounted on the platform lower section and protected against blasting consequences by 90 degrees tilt.

Such a solution assures obtaining a minimum illumination level on the shaft bottom of 20 luxes, according to requirements of respective standards in force. Obviously, in a zone which is not darkened by the operating equipment (as loader or other auxiliary machines), at normally applied height of the platform (approximately 20 meters above the shaft bottom) the obtained illumination level is considerably higher. The power supply unit mounted on the platform is supplied with 500 volts tension from the surface by means of a self-supporting shaft-type cable.

General Illumination System for Non-mechanized Heading Faces

In case of headings driven in stone, where, in majority, only compressed air is supplied, the only solution is application of turbine-type air lamps. The turbine-type lamps LTR-3, being produced now in Poland, are adapted to this particular purpose. They are equipped with mercury discharge lamp LRF-80 (80 watts), with corrected light spectrum, and give satisfactory strong luminous flux, approximately 3000 lumens. Rotational reflectors installed on the lamp enable the working personnel to direct the flux in a desirable direction and to protect themselves against glare.

To illuminate the face background zone, LTR-3 lamps should be mounted only, with spacing of up to 10 meters. In locating the lamps, attention should be paid to install them in such a way that satisfactory illumination of work places is provided. In case of electric power supply to the face, both mercury discharge lamps and incandescent or fluorescent lamps could be used for illumination.

According to the safety code, the mercury lamps over 125 watts and incandescent lamps over 150 watts must not be suspended lower than 2 m above the floor level, provided that they are equipped with special glare protective screens.

Before firing (blasting), all lamps exposed to striking should be removed from the hazardous area. It can be assumed on practical basis that in case of a heading driven in coal, the striking distance does not exceed 20 meters while in case of a heading driven in stone the distance is approximately 30 meters, counting from the front face.

Network Illumination System for Longwalls

Illumination Systems for Longwalls with Self-advancing Roof-support System

During the last years in the coal mining industry the predominating equipment was longwalls with self-advancing roof support system, mined by continuous miners. Applied illumination systems for such longwalls depend principally on their heights and types of roof support system.

In case of longwalls up to 2.0 meters high, multifluorescent lamps of OS 2 x 13 or Swit types are used. These lamps are supplied in 3-phase systems and mounted under roof-bars and, in case of lower longwalls, sometimes also between props, on the border of I and II fields.

For higher longwall illumination, use of mercury vapor lamps of 125 or 80 watts is widely preferred. Two types of the lamps are commonly used, one with the ballast built in, and the other with the ballast in a separate casing. The latter solution enables illumination of higher longwalls by means of lamps supplied by stub cable from the 3-phase main line.

To facilitate correct longwall illumination in underground mines, a special diagram has been elaborated. The diagram shows maximum spacing between the lamps, separately for various types of the lamps and in relation to the longwall heights.

Illumination System for Longwalls with Individual Supports

Operation of longwalls with individual roof supports is nowadays very rare in the coal mining industry while still and often applied in ore mines. Principal obstacle met at introduction of network illumination is a necessary relaying (moving) of a system, following the longwall advance. In case of lower longwalls, difficulties and strenuousness of jobs involved make practically unattainable the profits expected from general illumination systems. Consequently, the longwalls in lower ledges are rarely equipped with general illumination. On medium and higher longwalls, relaying is almost universally put into practice. In such cases, the mine crews prefer, rather, incandescent lamps because of their simpler construction and considerably smaller weight. These lamps are fed either directly from the main line or from a stub cable. The latter solution is willingly used on longwalls operated with hydraulic filling since the main line is installed along the scaled stopping and relayed jointly with it, once every few shifts.

All the longwalls, regardless the type of roof support applied, are equipped with signalling lamps of LU-40 type, mounted directly onto push-plate conveyors.

Individual Lighting for Mining Machines

Face Machines

The most typical for this group is a continuous miner. The problem of its lighting equipment has not yet been solved satisfactorily. Polish-made combined mining machines, either longwall or gallery type, are equipped with incandescent projectors, illuminating the operated section of the wall. Such a solution is considered inadequate and studies are continuing leading to modernization of the lighting equipment for the said machines. The first longwall continuous miner equipped with 8 W. fluorescent lamps was commissioned in Poland in February, 1972. The lamps built on it ensured general lighting of work places of machine personnel.

Self-propelled Face Machines

Self-propelled face machines used in Poland are equipped with both their movement route lighting and their working place illumination. Examples of applied solutions are shown on sketches of gadding car, loader, and anchoring machines. Another solution has been used for illumination of a pneumatically driven gadding car, where turbine reflector LTR-3, with 80 watts mercury discharge lamp, has been installed. This assures sufficient illumination of the whole face area.

Other self-propelled face machines have, for the time being, no possibility of sufficient illumination of the entire face area.

Mining Battery Lamps

In this chapter I would like to present briefly some of the solutions of mining battery lamps used in the Polish mining industry; namely, cap lamp RC-1 and lamp OP-1 for underground trains, portable LRS-3 lamp for rescue workers, as well as portable lamp for repair gangs.

Cap Lamp RC-12

Since a few years the RC-12 cap lamp has been introduced as an essential equipment of Polish miners. The lamp is equipped with a 3-cell cadmium-nickel battery (12 Ah, 3.6 V) and a bifilament bulb of 3.6 watts. Its luminous flux after 8 hours of continuous operation must not be lower than 20 lumens. Casing of this lamp is made from polycaproamid. Gross weight of the lamp is 2.4 kgs. The lamp is adapted for self-service charging system at constant voltage. Lamp rooms are equipped with 102-stand chargers.

End Lamp OP-1

This lamp is used to indicate the end of an underground train and has been shown on the drawing. The lamp is based on the same battery as used on the above-mentioned cap lamp RC-12. Additionally, it is equipped with a special head and a red bowl. This lamp is mounted on the last train car but is visible also from the front and locomotive. Battery charging is performed in a typical charger for the cap lamps RC-12.

Portable Lamp LRS-3

This lamp is provided for general illumination of a place of rescue action, in nonmethanic and methanic headings of low and high coal beds.

Operation principle of the lamp is the following: the current source of the lamp forms a battery of 8 RF type floating cells. The battery, capable only for a single use as a current source, requires no charging and a full electromotive force is obtained within several seconds of its immersion in an electrolyte made of sea water or, as a substitute, of an aqueous domestic salt solution with a concentration of approximately 3.5 percent. The battery stored in a dry condition in a protective bag, does not lose its electrochemical properties during a period of at least three years. Starting of the lamp takes place through inserting the battery into a container, connecting the battery conductors with the light source, and then floating the battery with electrolyte and closing the lamp cover. The lamp reaches its full burning capacity within 100 to 150 seconds from the moment of connecting the current source with the light source. After each discharge of the battery, preparation of the lamp for further use requires replacement of the used battery and electrolyte by a new, fully efficient battery and fresh electrolyte.

The lamp is provided with a wide-angle projector with an adjustable light distribution angle and a 15 watts incandescent lamp. The projector, movable in vertical direction, is fixed on the lamp cover by means of a metal tube. Inside the tube there are electric conductors connecting the incandescent lamp with the current source. Extension of the tube forms a lamp holder designed for carrying of the lamp in one hand. As a current source for this lamp, a battery of 8 floating cells of RF type, connected in series, activated by means of sea water, has been applied. The battery is housed in a container forming simultaneously the lamp base. For suspension of the lamp on the lining, a hook is fixed at the lamp holder. The explosion-proof casing of the lamp has been designed according to Polish standard. Total mass of the lamp amounts to approximately 8 kgs.

Lamp's luminous parameters:

- rated luminous flux - 220 lm
- lamp's true luminous flux - 140 lm
- light distribution angle - adjustable from 12° to 30°
- lamp's burning time - 8 to 10 hours.

Portable Lamp for Repair Gangs

Needs of mining crews are not limited to portable lamps illuminating locale of a rescue action. Also, repair gangs need to use a similar lamp to illuminate areas of their activities.

Because of respectively high costs of reserve batteries in LRS-3 lamps, an alternative design of the lamp is being prepared, based on a typical cadmium-nickel battery. Lighting parameters of this alternative solution would be kept unchanged; however, burning time would have to be reduced to 5 hours and weight of the lamp would increase about 4 kgs.

SUMMARY

Because of the time limits for presentation of the papers, this elaboration could not exhaust the subject of underground mine illumination in Poland. Nevertheless, its task will be fully secured if participants of the 2nd International Mine Lighting Conference form for themselves a judgment on the state of Polish techniques of underground mine illumination.

PROBLEMS OF ELECTRIC MINE LIGHTING IN THE WORK OF CIE

by

Adam Peretiatkowicz[1]

ABSTRACT

The paper describes first attempts in introducing electric lighting into the mines. Development work on illumination was since 1900 coordinated by International Commission on Photometry, which in 1913 transformed into the "Commission Internationale de l'Éclairage" /CIE/.

CIE included the problems of mine lighting in its work in 1931, establishing the Study Committee 29 "Mine Lighting." The paper characterizes the development of the work on mine illumination within CIE during the last 40 years.

Last of all, the present state of the work of Technical Committee TC-4.10 has been described, giving also some attention to the events organized by the Committee, as well as to its plans for the next years.

Implementation of the Electric Light into the Mines

In 1861, the first project of a mining electric lamp was worked out [1,2] Benois and Dumas, two Frenchmen, constructed portable electric lamp. It consisted of three main parts: zinc-carbon element, Ruhmkorft induction coil, and Geissler pipe. The Geissler pipe was giving a weak reddish light at current flow. In comparison with oil lamps, used then, the luminous flux

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of this lamp was 6.5 times weaker. By reason of that, this lamp could not be kept in use.

The first mentions of the use of electric light in mines refer to arc lamps installed aboveground. In 1879, electric lighting was introduced in Matylda Colliery in Świetochlowice. In the periodical "Zeitschrift für das Berg-Hütten und Salinenwessen" 3 of 1880 the information could be found that the East Field of the Matylda Colliery, the draving shaft bank and a part of the sorting plant had since been illuminated with electric lamp. Current was provided by the alternator with exciter, of Siemens-Halske, Berlin, for 4 arc lamps. These 4 arc lamps equipped with alabaster globes replaced 34 big kerosene or oil lamps used before in those rooms.

Practical application of arc lamps in the underground of collieries was difficult because of the hazard of methane mixture explosion or the ignition of coal dust suspension.

It was not until incandescent bulbs were developed and manufactured that the introduction of electric light underground became possible [4]. W. H. Uhland [3] wrote in 1884 in his book, "Das Elekrishe Licht": "Another domain in which incandescent light has found wider and wider application is mine lighting, where it is not only used to achieve sufficient lightness, but also to avoid the ignition of explosive mixture.

The incandescent light may be used for these purposes provided it is prepared for this by sufficient protection of the wires, the connections of which must exclude the possibility of sparking." A mine lamp has been constructed by Crompton/England/ using Swan bulb with a carbon filament. He closed the incandescent bulb tightly in an additional globe made of strong glass which he has protected with a protective grid of metal bars. Edison closed his mine lamp in a tight vessel with water. /In our country it is not possible to find any draft of this solution/.

In British mining industry, first trials of incandescent lamps [5] took place in 1881. In 1883, 20 Swan lamps were installed at a colliery in South Wales feeded from a Gramme generator /50 V DC/ located at the shaft bottom. All lamps were connected in series in a single circuit.

At the oldest Polish Salt Mine in Wieliczka - being in exploitation for 8 centuries, the electric lighting for mine shafts was introduced in 1881 [6]. In Silesia the first installation with incandescent lamps was built in Szombierki Colliery in Bytom in 1882.

International Commission on Illumination - CIE

The history of CIE is closely related to the development of science in the field of lighting. The beginning of their activity is connected with the Paris World Exhibition in 1900, when the International Gas Industry Congress under the chairmanship of Th Vantier, professor of the Lyon University, decided to establish an international association which would initiate photometric study of gas burners used for illumination.

In this way the International Commission on Photometry was established. Soon after that, the growth of electric lighting has forced the Commission to extend their activities to the problems connected with the construction and manufacturing of electric light sources, as well as their practical application.

As the result, during the Commission's Session in Berlin in August 1913, the resolution was taken establishing the "Commission Internationale de l'Eclairage" CIE/International Commission on Illumination/which was to continue the works in the field of lighting measurements initiated by the International Commission on Photometry and additionally take up new problems connected with the introduction of the new electric lighting into practice.

The activity of the CIE in the field of science and technology is based on the studies of the Technical Committee's TC and Study Groups SG, each of them having appropraite activity range assigned. At present, there are 26 TC and 1 SG acting within the CIE.

Twenty-nine countries participate in the CIE and 9 other countries have a status of the associate members.

CIE Work on Mine Lighting

Problems of mine lighting became of interest to CIE not before 1931.

In September this year, the 8th Session of the CIE took place in Cambridge. At that session the individual paper was presented by W. Maurice /GB/: "A Standard of Illumination for Mines" and after discussion the resolution was taken to include mine lighting in the CIE studies.

As a consequence, Study Committee 29 "Mine Lighting" was established, the secretariat being allocated to Great Britain [7]. The terms of reference of the new Study Committee were defined as follows: "to study the regulations and methods used in the lighting of coal mines /personal and general lighting/".

The Committee prepared an international enquiry sheet with questions to the construction of the mine lighting equipment, its application, obligatory regulations, etc. Replies to this enquiry were received from 8 countries.

In July 1935, the 9th Session of the CIE took place in Berlin and Karlsruhe. An extensive report of the Committee, including a detailed analysis of the answers obtained from the 8 countries, was presented [8] and the working program of the Committee, for the next period, was somewhat widened. The most important tasks were to obtain measurements of illumination in the mines of the member countries, and to study the influence of illumination and glare on efficiency and safety.

For the next quadrennium 1935-1939, the responsibility for the Committee was committed to Germany. In 1939, the 10th Session of the CIE was held in Scheveningen, Holland. The Committee presented a report [9] and individual papers were presented, such as: "Illumination and miner's nystagmus" by J. Wellwood-Ferguson /GB/ and "Changing requirements and lighting factors for coal and metal mining in USA" by Carl E. Egeler /US/ and "Stand und Entwicklungsmöglichkeiten der Beleuchtung in Schlargwettergeschützten Steinkohlengruben" by K. Nehring /D/.

The 11th Session of the CIE took place in 1948 in Paris. The report prepared on the basis of the enquiry launched in 1947 was presented, and an individual paper entitled "Fluorescent Lighting in Mines" was given by Dr. F. W. Scharplay and R. Crawford /GB/. Belgium took over the secretariat for the next period /1948-1951/.

The 12th Session of the CIE took place in 1951 in Stockholm. Individual papers were presented: "Dark Adaptation and Miner's Nystagmus" by J. W. Ferguson and F. W. Scharpley /GB/ "Problems Associated with Underground Lighting in British Coal Mines," by D. Strachan /GB/. Official CIE recommendations agreed at the 12th Session advised the Committee.

1. To work on the determination of:

   - the visibility level required by different works in mines
   - the possibilities of reducing glare and of improving the visual conditions underground by whitening dark surfaces or by spraying them with bright stone powder
   - the economical profits arising from the introduction of lighting related to the amount of coal excavated and to the costs of labour
   - the glare coefficient at the illumination levels obtained at that time at the underground works

2. To ask the National Committees to prepare practical recommendations for analysis and comparison at the next CIE Session.

In 1951, as part of a reorganization of the CIE, the Mine Lighting Committee became Secretariat Committee 3.1.5. with Belgium as Secretariat Country.

The 13th Session of the CIE took place in Zürich. As well as a Secretariat Report, the following papers were discussed:

a. J. Patigny /B/: Étude sur la visibilité dans les mines

b. W. J. Wellwood Fergusson /GB/: Darka adaptation and miner's nystagmus

C. W. Young /GB/: E. L. Potts, W. B. Bell /GB/: Lumen method
of design for mine lighting installations.

The Secretariat remained with Belgium for the next period, 1955-1959.

At the 14th Session of the CIE in 1959 in Brussels, a report on the technical progress in mine lighting in Poland, presented by the Polish Mine Lighting Committee, raised considerable interest and the Secretariat was transferred to Poland for the period 1959-1963.

The 15th Session was in 1963 in Vienna. A proposal to change from a Secretariat to an Expert Committee did not meet with the approval of the CIE Action Committee. The determining reason for this refusal was the regression in coal mining at that time in West Europe and USA. The Secretariat was committed to Great Britain for the years 1963-1967.

The 16th Session of the CIE took place in Washington. As well as a Secretariat Report, the following papers were discussed:

- W. B. Bell and I. Lewin /G.B./ "The Application of Photographic Photometry to the Lighting of Tunnels"
- A. G. Neil /G.B./ "Features of the Modern Miner's Lamp"

In this Session the Action Committee decided to include the Secretariat Committee S-3.1.5 into the new Expert Committee E-3.1.2. Interior Lighting. So the Secretariat Committee S-3.1.5 Mine Lighting was discontinued.

Technical Committee TC-4.10 Mine Lighting

In June 1971 during the 17th Session in Barcelona, Dr. A. Peretiatkowicz submitted the proposal for establishing a Study Group to deal with the problems of mine lighting. The Board of Adminsitration of the CIE considered this and consulted the National Committees. The increase in coal production was again of interest and underground mining became once more a growing industry.

In September 1975, at 18th Session of the CIE in London, the Polish proposal of Barcelona was accepted and the CIE Board decided to establish Technical Committee 4.10 "Mine Lighting" with Poland taking the lead.

TC-4.10 started its activity at the end of 1975; in this time 16 countries have designated their representatives for collaboration within the Committee.

The first working program of the Committee has been approved by the CIE Board of Administration in 1976. Its main task was to prepare international recommendations for the underground mine lighting, to make a worldwide survey of mine lighting practice, and to prepare mine lighting vocabulary comprising terms and their definitions.

The first TC-4.10 meeting in which participated 12 delegates from 5 countries, was held on 2-3 October 1978 in Jaszowiec /Poland/.

At the meeting the terminology of mine lighting for the 4th edition of the CIE was accepted and the initial data for the international recommendations of underground mines lighting were discussed and coordinated.

It has been decided to establish a Subcommittee on lighting measurement in mines and to organise the next International Conference on Mine Lighting in 1981. The work of the Committee connected with preparation of the 19th Session of the CIE in Kyoto was also discussed.

This meeting was joined with First International Conference on Mine Lighting held on 4-5th October 1978 in Jaszowiec. In the Conference took part 180 persons and there were presented 16 papers which referred to mine lighting technology in the United States, France, Belgium, Czechoslovakia, and Poland. Approved at Jaszowiec - 45 terms with definitions, in five languages, within the range of mine lighting were submitted at the meeting of TC-1.1 "Terminology" in Paris on 22nd November 1978. After discussion, 21 of them were accepted to be included into the 4th edition of the CIE as an additional sub-chapter "Mine Lighting."

The second TC-4.10 meeting was held in August 22-23, 1979 during the 9th CIE Session in Kyoto. In meeting, 22 delegates from 12 countries took part. At the meeting, the Chairman presented the Quadrennial Report of TC-4.10, which after discussion, was approved.

In this report the scope of activity and working programme of the Committee for the quadrennium 1975-1979 were given. There was also discussed the work connected with organization of the Committee with emphasizing the frequent fluctuations of its consitution.

Furthermore, the report included work of the Committee proposed for the next quadrennius, the bibliography comprising the years 1971-1979 and a brief discussion of the more essential directions of work being conducted in world's mining for improving illumination in underground mines.

At this meeting, Dr. A. Peretiatkowicz presented his paper: "Examination of Perception Level in the Conditions of Mesopic Vision." This paper contains the results of examination of perception of black-white and colour tests plates, carried out by the author in photometric laboratory. The test plates were selected to meet the needs of an underground miner and illumination conditions, as well as the values of coefficient of reflection, were chosen to correspond as much as possible to the conditions of underground workings in hard coal mines.

The results obtained have allowed to determine minimum luminance levels indispensable for safe and efficient work of the miners being employed underground.

TABLE 1. - Countries participating in the work on mine illumination

	Study Committee 29				Secretariat Committee S-3.1.5				Technical Committee TC-4.10	
Years	1931	1935 1939	1947	1948	1951	1955	1959	1963 1967	1975	1979 1983
Leading Country	Great Britain Prof. Wheeler	Germany Mr. Schneider	Belgium Mr. Brison	Belgium Mr. Brison	Belgium Mr. Brison	Belgium Mr. Brison	Poland Dr. A. Peretiatkowicz	Great Britain Dr. A.G. Neil	Poland Dr. A. Peretiatkowicz	Poland Dr. A. Peretiatkowicz
Countries Participating in the Work					Australia		Australia		Australia	Australia
						Austria				
	Belgium		Belgium	Belgium	Belgium	Belgium	Belgium	Belgium	Bulgaria	Bulgaria
						Canada	Canada	Canada	Canada	Canada
				Czechoslovakia			Czechoslovakia	Czechoslovakia	Czechoslovakia	Czechoslovakia
				Denmark						Denmark
				Finland					Finland	Finland
	France	France	France		France	France	France		France	France
	Germany	Germany			Germany	Germany	Germany	Germany	Germany	Germany
	Great-Britain	Great-Britain	Great-Britain		Great-Britain	Great-Britain	Great-Britain	Great-Britain	Great-Britain	Great-Britain
							Hungary	Hungary	Hungary	Hungary
		Italy	Italy			Italy	Italy	Italy		Italy
							Japan		Japan	Japan
	Netherlands	Netherlands	Netherlands				Netherlands	New Zealand		Netherlands
	Poland					Poland	Poland	Poland	Poland	Poland
								Rumania	Rumania	Rumania
						South-Africa			South-Africa	South-Africa
	Sweden		Sweden			Sweden		Sweden	Spain	Spain

TABLE 1. - Countries participating in the work on mine illumination
(continued)

	Study Committee 29					Secretariat Committee S-3.1.5					Technical Committee TC-4.10		
Years	1931	1935	1939	1947	1948	1951	1955	1959	1963	1967	1975	1979	1983
Countries Participating in the Work	USA	Switzerland USA		Switzerland USA	Switzerland USA	USA	Switzerland USA Yugoslavia	USA USSR Yugoslavia	USA USSR		USA USSR	USA USSR	

The third TC-4.10 meeting, in which participated 18 delegates from 9 countries, was held on 21-22 April, 1980 in Kokotek /Poland/. During this meeting, 3rd draft of the CIE Recommendations for underground mine lighting was discussed. Next, the following projects were submitted to be discussed:

- further work on mine lighting terminology - accepted to be published in the TC-4.10 Report,
- working programme of the Subcommittee SC-4.10B Open Cast Lighting

Prof. Trotter presented an example of Canadian experiments regarding light sources. They wanted to change the tungsten filament bulb to a quartz hilide bulb and felt this would be a great breakthrough in cap lamp design. After discussion on this subject, the Chairman proposed to set up a new Subcommittee SC-4.10C Mine Light Sources, led by Professor Trotter. This proposition was approved and new subcommittee established.

At this meeting, and as well at the 2nd International Conference on Mine Lighting, the collaboration with other Technical Committees and the programme of the 4th meeting of TC-4.10 planned to take place in Beckley, U.S., in 1981 were discussed.

The 3rd TC-4.10 meeting was joined with the International Symposium, which took place at the Mining Museum in Zabrze and was devoted to a hundred years of electric lighting in Silesian collieries. The history of electric lighting in underground mines, presented at the Symposium, was completed by the displays [in the Museum] of old lamps and new mine lighting equipment by Poland manufacturers.

In Table 2 the present membership of TC-4.10 is shown. As well, the participation of the National Committees in the TC-4.10 work is made evident.

The 4th TC-4.10 meeting will be organized by the U.S. National Committee. It will be held in Beckley, WV, in October 12-13, 1981, and will be joined with the 2nd International Conference on Mine Lighting, October 14-15, 1981, and displays of lighting equipment by U.S. manufacturers.

TABLE 2. - Countries participating in work of the TC-4.10 mine lighting - March 1981

Country	Designated Representative				National Committee of Mine Lighting
	TC-4.10	SC-4.10.A	SC-4.10.B	SC-4.10.C	
Australia	Mr. J. Munro	Not yet appointed		Not yet appointed	
Bulgaria	Mr. G. Ganchev	Not yet appointed		Not yet appointed	
Canada	Prof. Donald Trotter	Prof. Donald Trotter		Prof. Donald Trotter	Collaborates with TC-4.10
Czechoslovakia	Mr. M. Lazar		Not yet appointed	Not yet appointed	
Denmark	Mr. H. Hilsøe				
Finland	Mr. R. Heikkinen				
France	Mr. R. Deniau				Exists
Germany	Dr. B. Weis	Not yet appointed	Not yet appointed	Not yet appointed	
Great Britain	Mr. G. Heatherington	Not yet appointed			Exists
Hungary	Mr. P. Esztegar				
Italy	Pr. G. Gecchele			Not yet appointed	
Japan	Mr. S. Kato				
Netherlands	Dr. F. Burghout				
Poland	Dr. A. Peretiatkowicz	Mrs. B. Plebankiewicz	Mrs. Barbara Kolesnik	Not yet appointed	Collaborates with TC-4.10
Rumania	Mrs. E. Sufrim				
South Africa	Mr. R. Hemp	Dr. H.H.E. Schröder	Not yet appointed	Mr. J.P.M. Hojem	Collaborates with TC-4.10

TABLE 2. - Countries participating in work of the TC-4.10 mine lighting - March 1981
(continued)

Country	Designated Representative				National Committee of Mine Lighting
	TC-4.10	SC-4.10.A	SC-4.10.B	SC-4.10.C	
Spain	Dr. S. Cutillas				
United States	Mr. Cecil Lester	Mr. William Lewis	Mr. Kenneth Whitehead		Collaborates with TC-4.10
U.S.S.R.	Mr. N. B. Machugovsky				

Note:

Subcommittee SC-4.10.A	Mine Lighting Measurements	Chairman: Mr. W. Lewis
Subcommittee SC-4.10.B	Open Cast Lighting	
Subcommittee SC-4.10.C	Mine Lighting Sources	Chairman: Prof. D. Trotter

Not yet appointed - this country declared to appoint its representative to participate in Subcommittee

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8. Mine Lighting in the work of CIE, CIE Bulletin No. 36, April 1979

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TITLE OF PAPER: Modern Underground Lighting Techniques.
New Material Which the Lighting Fittings
Consist of; Suitable Constructions and
Practical Testing

AUTHOR: Ing. Georg Pawlowski
Messrs. Adolf Schuch KG
Worms am Rhein
Federal Republic of Germany

Mr. Pawlowski has been responsible for the development and construction of explosion proof and mine-gas-proof fittings at Messrs. Adolf Schuck KG, for 14 years.

MODERN UNDERGROUND LIGHTING TECHNIQUES NEW MATERIAL WHICH THE LIGHTING FITTINGS CONSIST OF; SUITABLE CONSTRUCTIONS AND PRACTICAL TESTING

by

Ing Georg Pawlowski[1]

ABSTRACT

The modern highly developed technics at the working place are more and more prevailing and consequently demand requirements of the lighting technics which are still higher as far as mining is concerned. The very difficult underground working conditions are the major reason for this development.

Good lighting proportions are most essential for increasing the productivity.

For effectively avoiding any demolition of the lighting equipment by mechanical or, above all, by chemical influences (corrosion), new materials have been created and meanwhile already tested over long periods. The housings of lighting fittings which are made of glass fibre reinforced polyester have proved a success for instance with regard to chemical influences in the mine existing there from nature in combination with the synthetic chemicals additionally brought-in such as antidust pastes, increased possibility of corrosion - see detailed explanation.

As a matter of fact the enormous mechnical demands have been taken into consideration with regard to plastic lighting fittings.

The danger of a possible ignition of explosive methane (CH_4) mixtures as a result from an electrostatic charge through the combination of plastic housings and the dust particles accelerated by the ventilation has meanwhile been scientifically investigated during a special research program by the Institute for Explosion-proofness and Explosion Technics.

The results which are available will be explained verbally.

Improvement of the drift lighting,
lighting fittings for 2 x 65 W fluorescent tubes,
photographs and explanations;

uniform electricity supply systems;
adjustment of the supply voltage for machines,
appliances and lighting fixtures, 500 and 1000 volts.

cold cathode fixtures, supply voltage 1000 volts
in the mining, shock-proof, shot-proof;

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[1] Messrs. Adolf Schuch KG, Worms am Rhine, West Germany

visual projection

visual projection of ab. 20 - 25 diapositives of new floodlight systems of a very high luminous efficiency. Such floodlights are suitable for drill carriages, mining machines, locomotives and stages as well as for TV monitoring of automatic loaders, filming, etc;

Report on projected lighting systems of the enclosure "Sch" i or new "Ex" I i, for instance several small luminaires connected with a supply unit of high frequency voltage (not yet ready for mass production).

INTRODUCTION

In contrast to the previous lectures given, the basis of which has been the science, I would like to call your attention to a subject which seems to be a bit more concrete than the others.

You know, before talking about the direction of light, the measurement of light or even about underground glare and reflection, we first have to see to it that the necessary preconditions are fulfilled.

And this is what I am intending to talk about today.

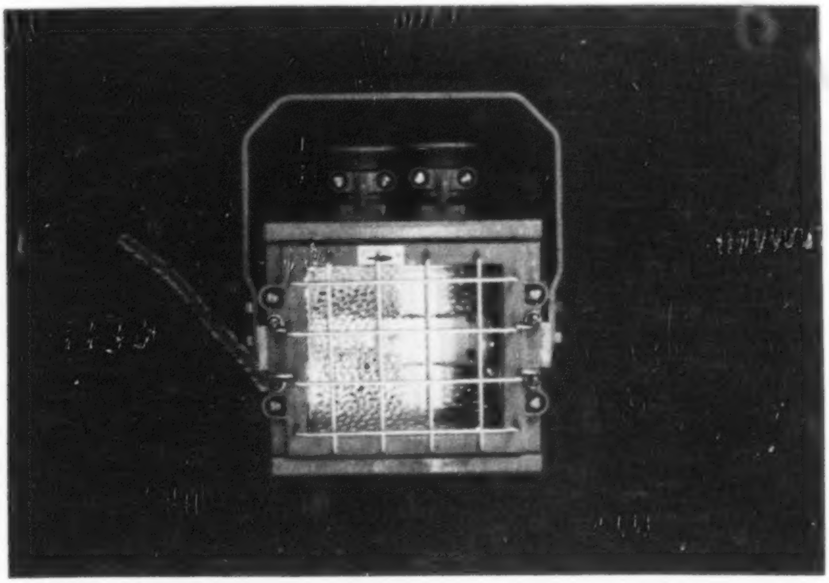
MODERN LIGHTING TECHNIQUES, MATERIALS, CONSTRUCTION AND TESTING

The modern highly developed technics necessarily are more exacting, as far as the technical side of the underground lighting is concerned, since above all mine working is possible only under very difficult conditions.

Due to the enormous quantity of dust resulting from drilling work and from shooting and blasting, as well as because of the dust near coal and stone cutting machines, it is imperative that the lighting equipment is optimum and that its functioning is excellent so that an economic winning is guaranteed.

The following figures illustrate floodlights which have been developed particularly for this field of application.

Figures 1 and 2 show a fixture using lamps, which are of the type already used by the motor car industry, are tungsten halogen lamps having a particularly strong filament that is positioned in a very short distance. There are two such lamps of 24 volts, 70 watts, arranged in series in one floodlight housing. The supply voltage being 42 V, the lamps are operated with undervoltage, which fact is very advantageous for their life. It will be 3 to 5 times as much as the usual life of this type of lamp; the halogen circulation will not be impaired.



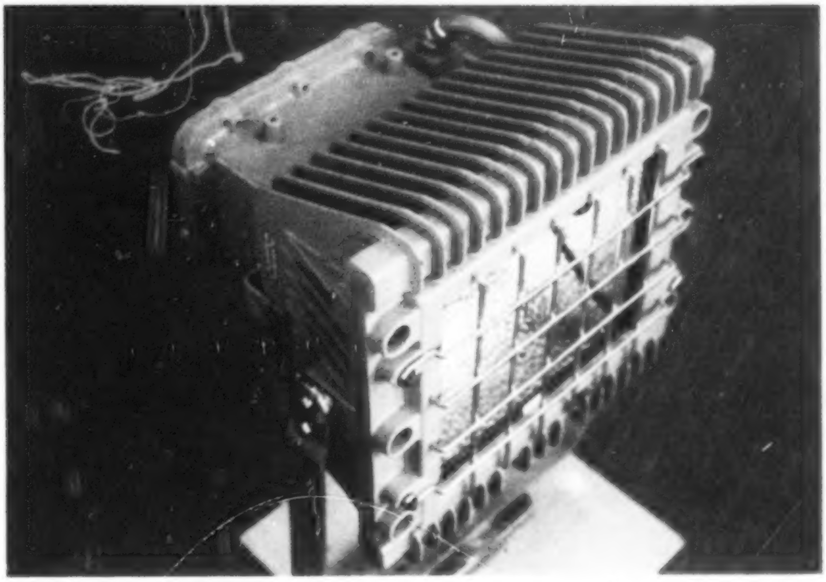


FIGURE 1. - Front view of tungsten halogen floodlight.

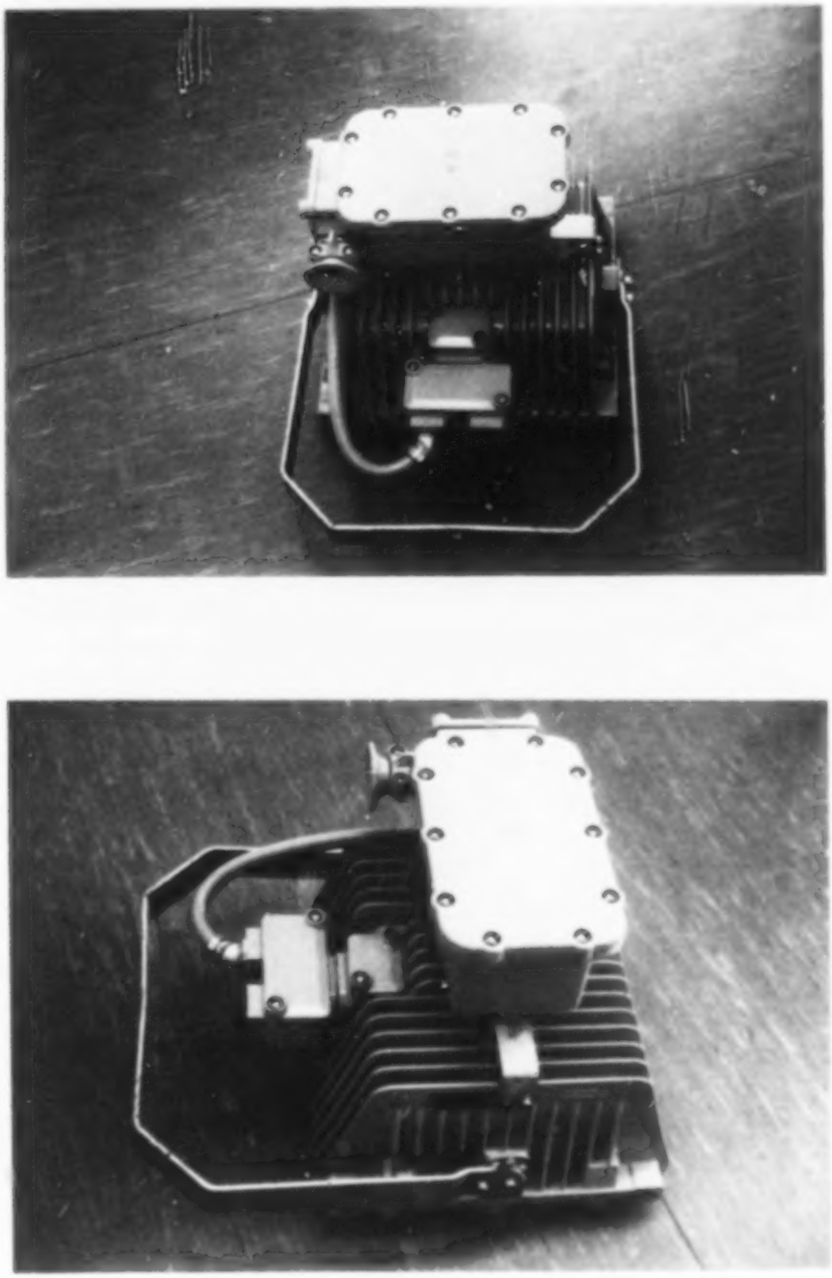


FIGURE 2. - Junction box on rear of tungsten halogen floodlight.

Lighting fixtures of this type have proved best for fixation on winning machines. Originally, the standard incandescent lamps had to be replaced up to five times per shift, whereas the aforesaid tungsten halogen lamps have had a life of four months already, although the machines worked 18 hours per day.

Larger floodlights of the simular design are also available for lamps up to 1000 watts. Figure 3 illustrates these floodlights on a mining machine.

The housings of these lighting fixutes are made of a selected aluminium alloy.

In future this will no more be possible. According to the New Recommendations EN, it has to be brass.

The construction of such machines allow the fixation of lighting fittings which are bulky to such a degree.

As to the shield-type support, however, the construction of the lighting fixtures had to be suited to the prevailing mechanical conditions. Even if the shield is lowered, the construction of the luminaires must not all be troublesome.

In order to meet the requirements of illumination, such lighting fixtures have to be arranged in small distances (Figure 4).

Figure 5 shows a longwall face with shield-type support.

These luminaires, the housings of which preferably are made of sheet steel, have been equipped with cold cathode lamps for several years:

a. in order to increase the luminous efficiency and

b. in order to have a sturdy lamp mostly of the Meander shape, the life of which is very long.

These lighting fixtures have meanwhile been constructed such that the lamp and the ballast which represent one only unit (encapsulated by means of silicon caoutschouc or another similar product) can be exchanged very easily without having to switch off the light.

The cover of the fixtures is made of transparent polycarbonate (Makrolon); thus, any destruction through stoning or the like is avoided.

The parts employed being injection moulded ones, the advantages of this method of production have, of course, been very useful by providing the inside of the parts with a prismatic structure opposing a relative glare.

Due to the fact that by far not yet all longwall faces have been equipped with shield-type supports, the proved incandescent lamp (Figure 6 and 7)

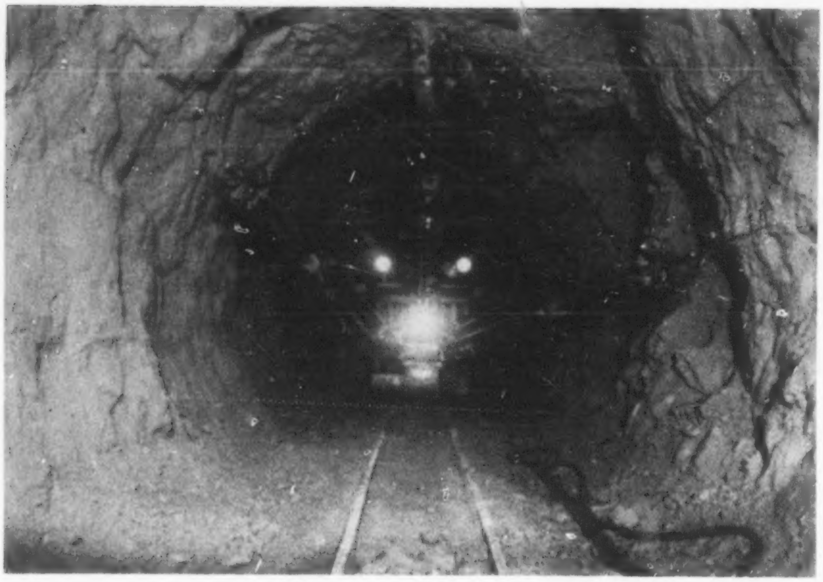


FIGURE 3. - Tungsten halogen floodlights mounted on mining machine.

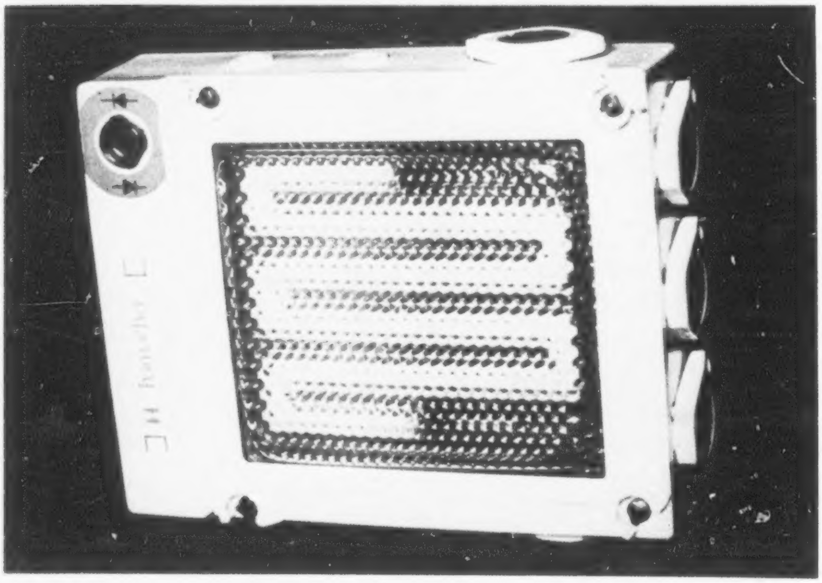
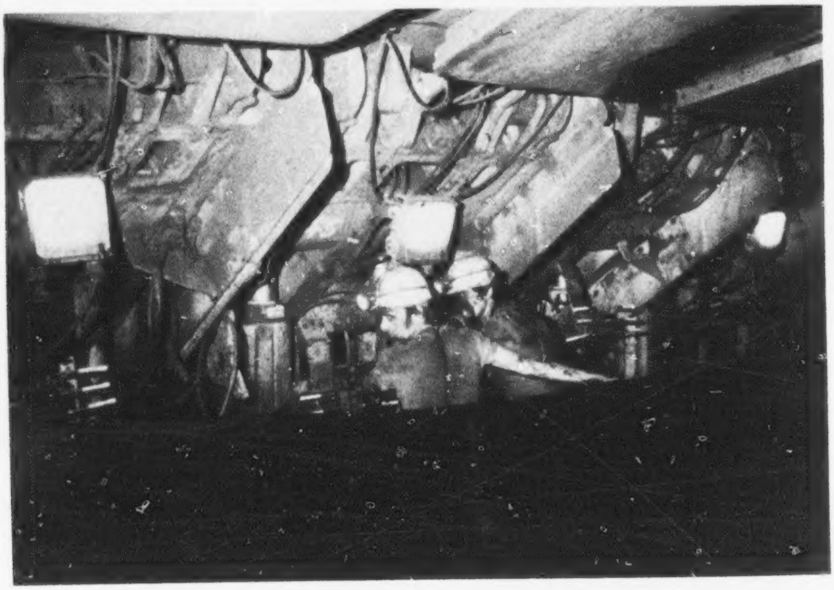


FIGURE 4. - Lighting fixture designed for use on shield-type longwall supports.



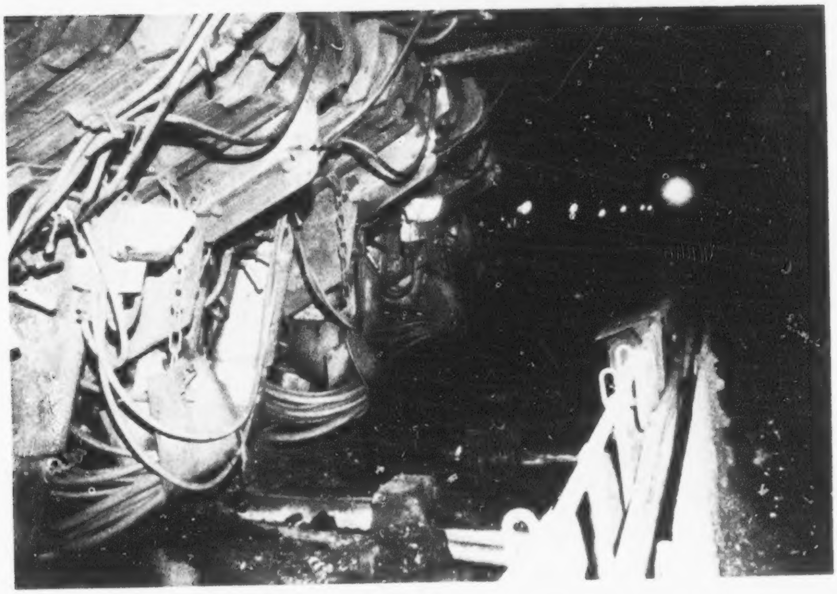


FIGURE 5. - Application of shield-type lighting fixtures on longwall face.

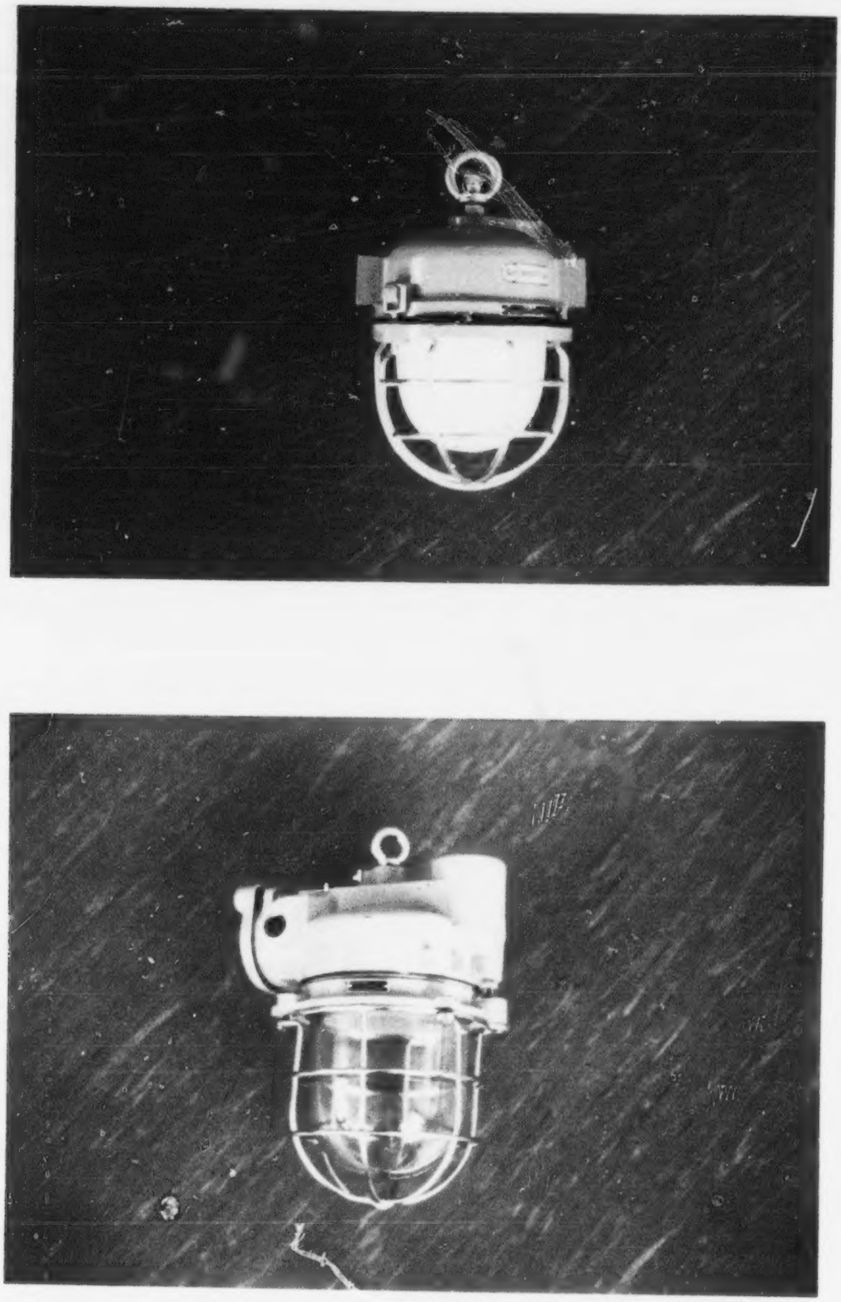


FIGURE 6. - Incandescent fixtures for underground applications.

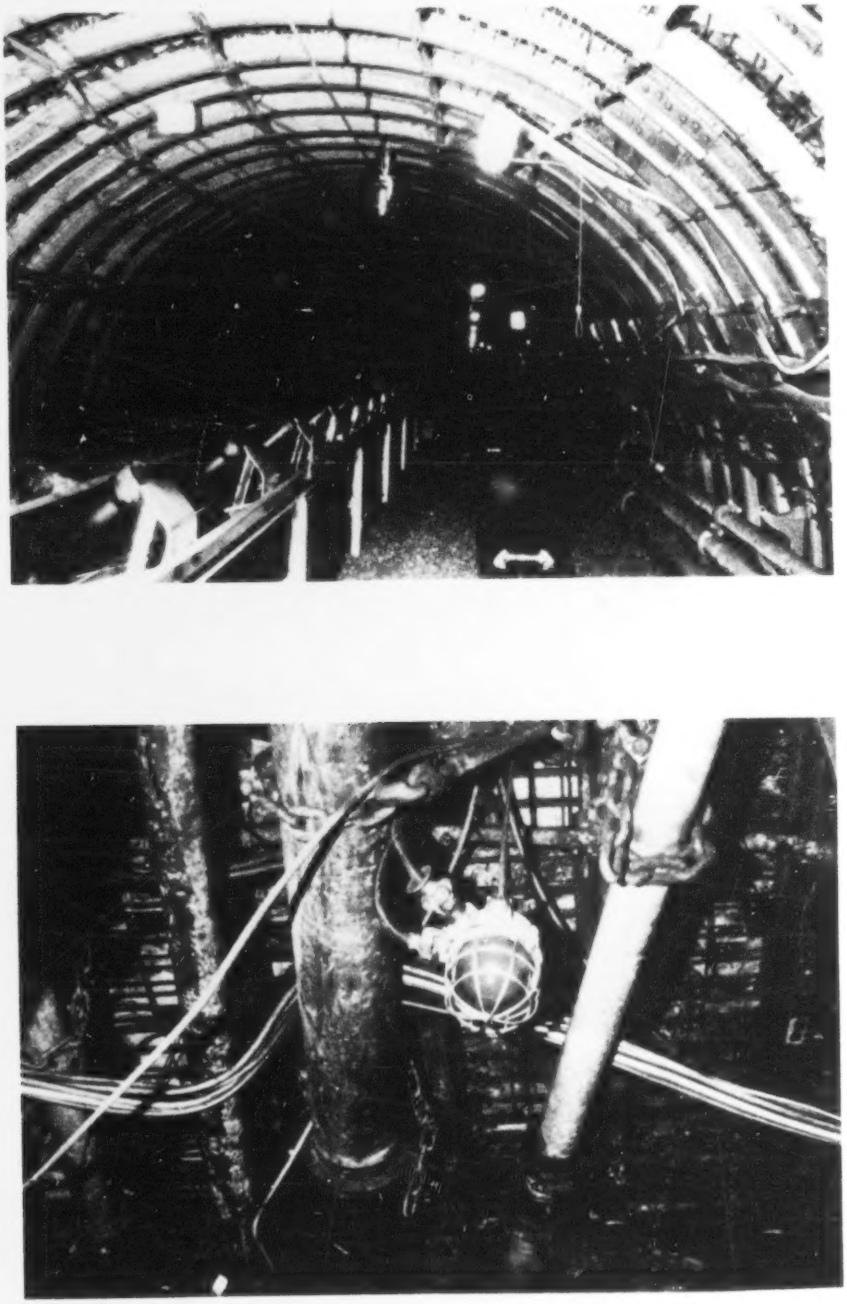


FIGURE 7. - Applications of incandescent-type lighting fixtures.

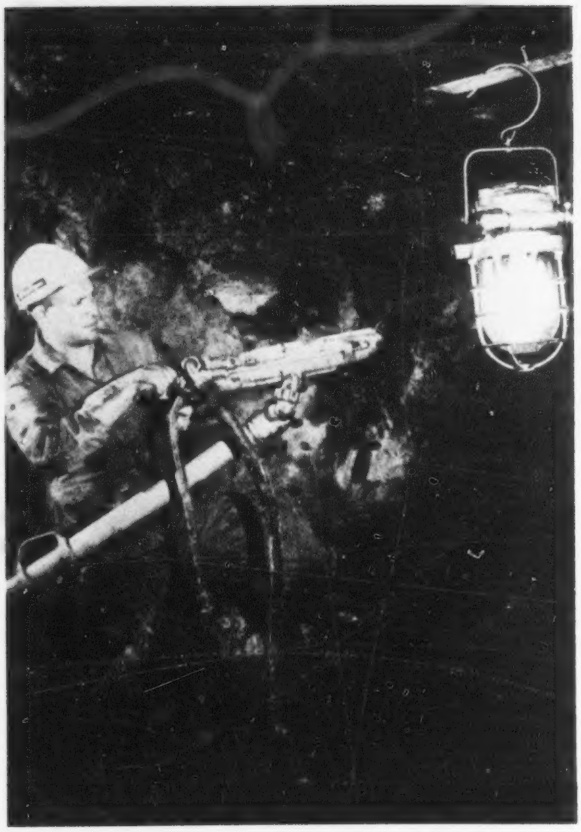


FIGURE 7 (Continued). - Applications of incandescent-type lighting fixtures.

fitting made of grey cast iron is still used, and of course, also the comparatively short fixtures for 2 x 20 W fluorescent tubes are installed (Figure 8 and 9).

Their housings are mostly made of polyester but sometimes they are also made of sheet steel. You can say that lighting fixtures for fluorescent tubes are the most advantageous kind of illumination as far as the economical side is concerned.

Even lighting fixtures for 2 x 40 W are installed, if longwall faces of large sizes have to be illuminated, and recently 2 x 65 W tubes have been employed because of their considerably higher luminous efficiency (Figure 10).

In the course of the past years, it has been found out that lighting fixtures with housings of polyester resin reinforced by glass fibre mats, are much more resistant to mechanical and to chemical dangers than the fixtures with sheet steel housings.

Chemical products available in the mines are an increased danger of corrosion for all metallic parts in combination with synthetic additional ones, such as antidust compounds.

Glass fibre reinforced polyester (GFUP) is extremely well suitable for usage in corrosive underground atmospheres. One does not know any case at all, neither of decay nor of decomposition of polyester products, resulting from chemical reactions.

The application of several impregnated glass fibre mats consisting of several layers represents a sort of reinforcement that makes the mechanical stability of these housings equal to that of sheet steel housings at a very high modulus of elasticity ($E = 8000\ N/mm^2$).

In this connection I still wish to mention that this kind of material has got a very high tracking resistance and that consequently it is well suitable for carrying various potentials (for example: inserted connection terminals).

KA = 380 V, determination of drop number up to short circuit; leak trace

KB = determination of voltage at 50 drops maximum.

The dangers of a possible ignition of explosive methane gas mixtures as a result of an electrostatic charge, through the combination between plastic housings and dust particles accelerated by the ventilation, have meanwhile been scientifically investigated on the occasion of a special research program.

The institute for Explosion Proofness and Shooting and Blasting Technics in Dortmund, Germany, has found out - when effecting numerous experiments -

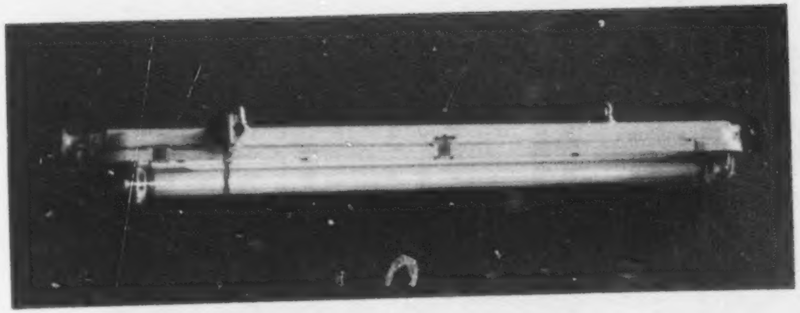


FIGURE 8. - Underground fluorescent fixture.

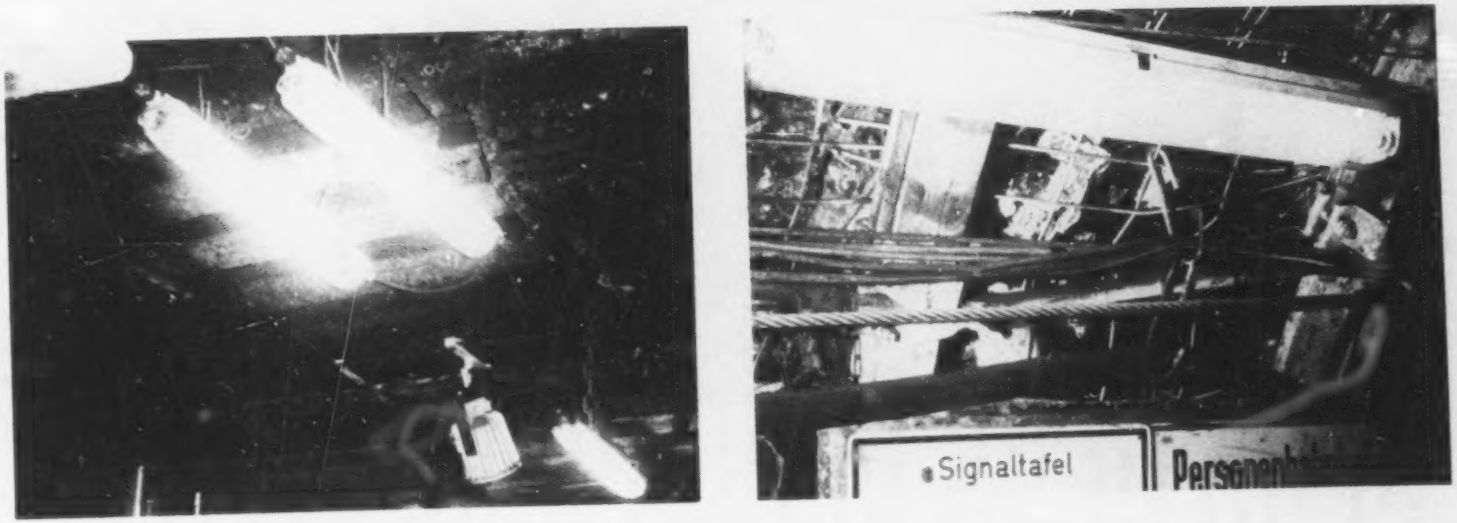

Signaltafel
Personen

FIGURE 9. - Underground installations of fluorescent fixtures.

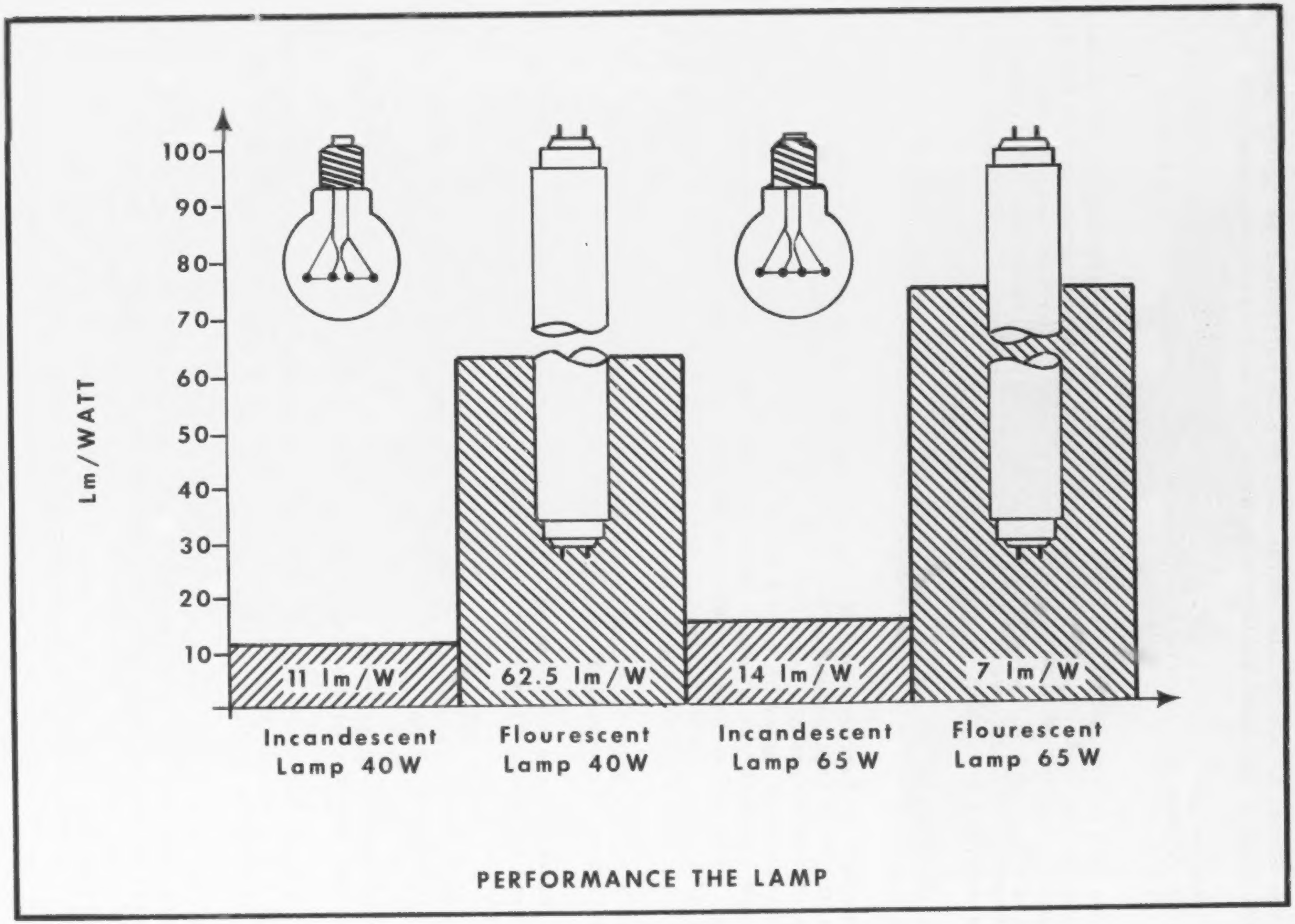


FIGURE 10. - Comparison of tungsten and fluorescent lamp performance.

that the energy of a possible charge will not be sufficient to ignite any mixture of good ignition quality even under the most favourable conditions.

Consequently, you can say that furthermore there are all possibilities of using without any restriction products which are made of this kind of material.

Another innovation with regard to the lighting engineering is the accommodation of the lighting fixtures and of their inner components to the supply voltages of 500 and of 1000 V prevailing in mines. For that purpose the lighting fixtures for fluorescent tubes are equipped either with additional transformers or, with special ballasts having incorporated transformers which can be switched over from 500 to 1000 V.

With this move it is intended to realize a considerable step of rationalization.

Meanwhile, further new lighting systems of a comparatively new type of protection have been developed for the underground installation. Such systems of illumination of intrinsic safety are available for a miximum of six small fluorescent tubes of 6 or 8 watts or for 5 such tubes of 15 watts each which are operated via a common generator of a small but high frequency voltage. Similar systems are applied already in United kingdom and in the United States of America; however, they have not been approved in Germany because of the different regulations.

So far this kind of illumination has not been used with success in Germany for pure economical reasons.

A research program welcomed by the German Research Minister is said to contribute to making this lighting system economical and mature for mass production.

Another research program is dealing with the development of a new "personal miner's" lamp.

This work of engineering still being in the early stage, I am able of talking only about what the Adolf Schuch Company has done so far.

It is our intention to create a system that has some advantages compared with the types which are presently on the market and which comprise a helmet and an attachable lighting fixture with Ni-Cd-battery (Figure 11).

The miner's lamp known has a few disadvantages which render the minor's work more difficult by reducing his freedom of motion. It is fixed to the front side of the helmet, thus causing a certain inbalance of the protective headwear. According to the result of consultations and investigations, such an inbalance may lead to unconscious wrong positions of the head and consequently to early symptoms of tiring.

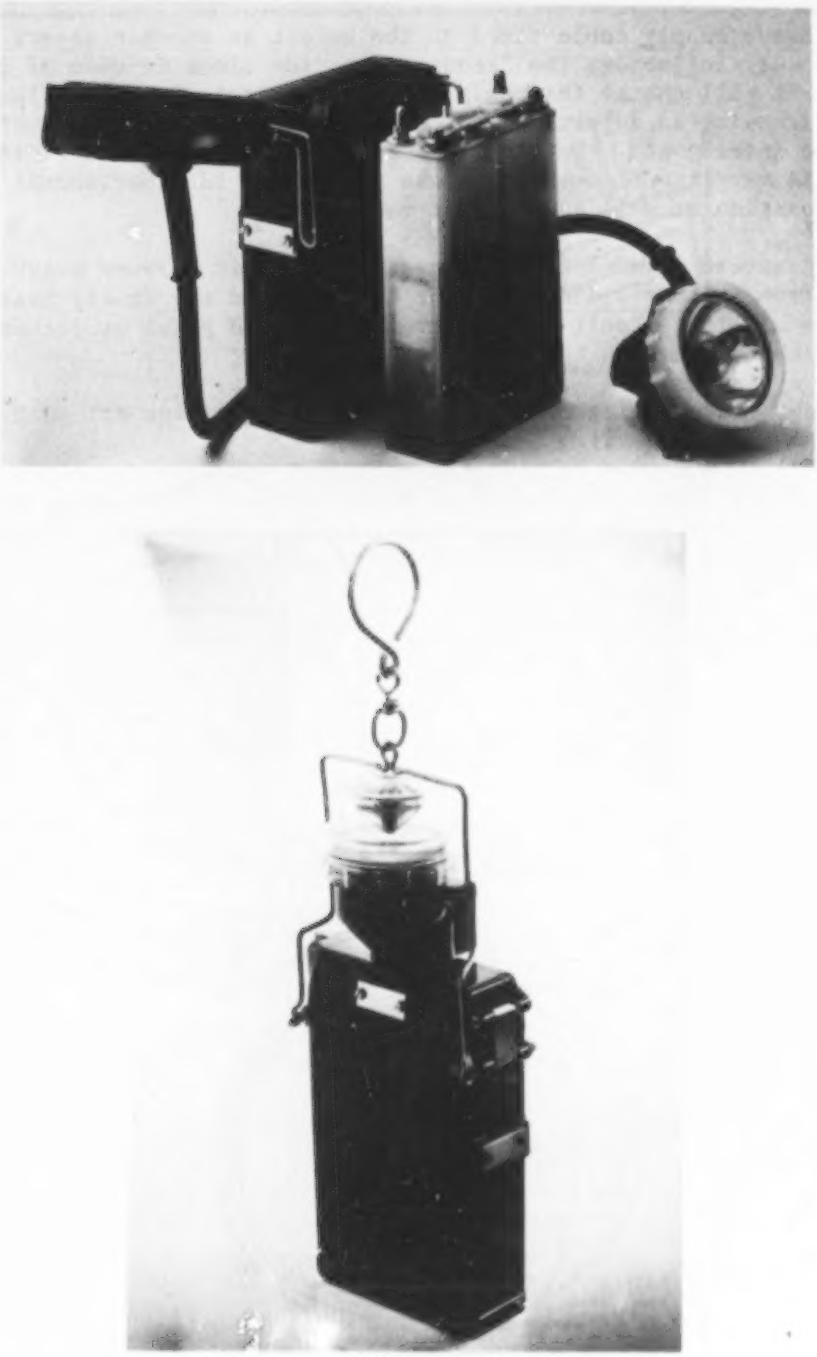


FIGURE 11. - New personal miner's lamp.

The heavy supply cable fixed to the helmet is another object that disadvantageously influences the freedom of motion since in case of certain movements it will change the position of the helmet and of the lamp. This fact will require an adjustment which means that the work will, of course, have to be interrupted. Due to its shape the source of electricity fixed to the belt is very troublesome for works to be made in a horizontal or in a cowered position as well as for belt runs.

The greatest disadvantage, however, is that it is very heavy and that as a result from its one-sided fixation, it will lead the faulty bearing as well. The source of light itself is an extremely bundled point projector thus causing too much contrast in the light/dark zone.

The new system being developed is said to eliminate all such disadvantages (Figures 12 and 13).

The new cap lamp; the design of which is based on numerous economical, medical, and ergonomical investigations, as well as on those of lighting engineering, will offer considerable advantages on the whole.

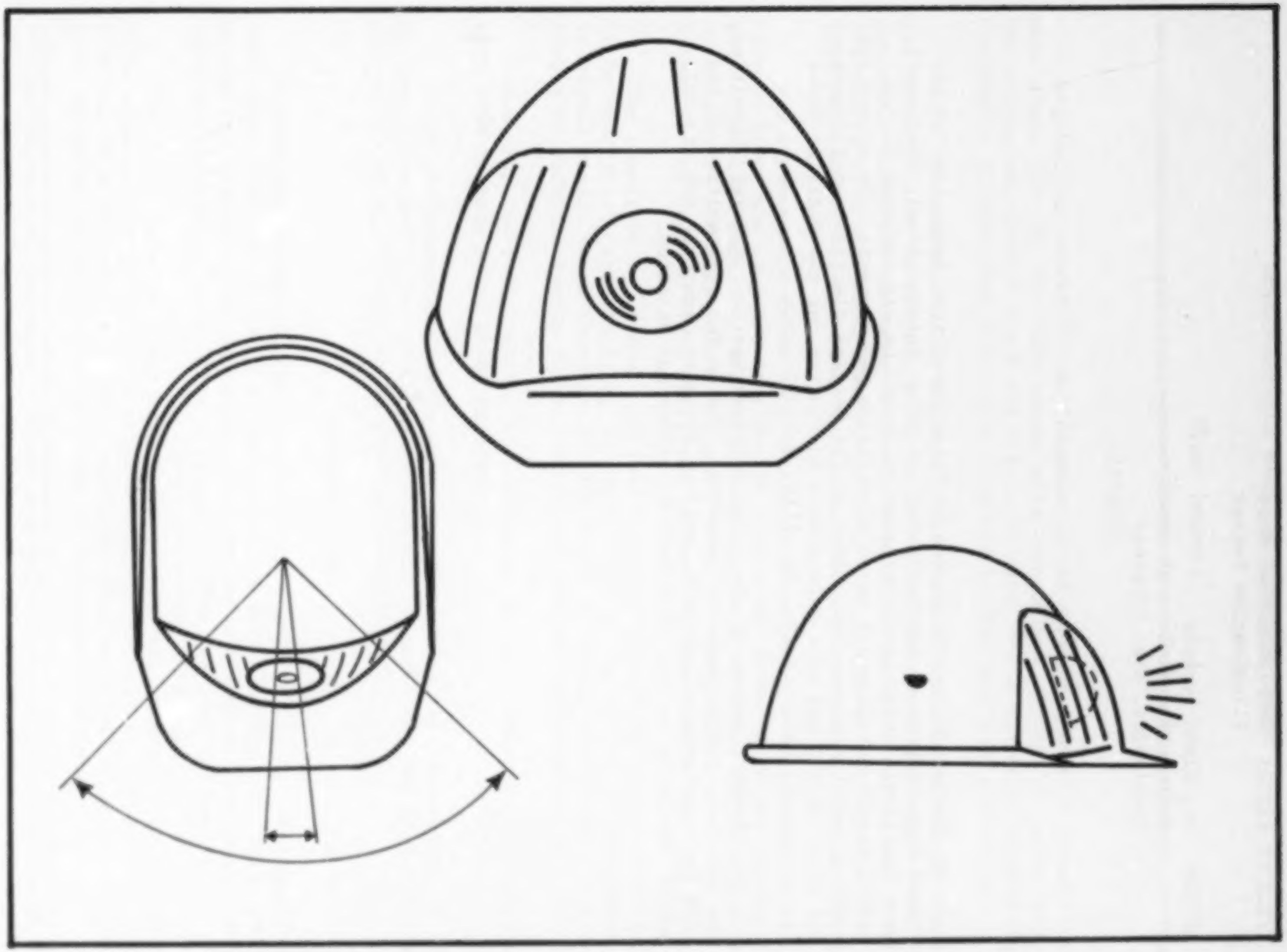


FIGURE 12. - Front, top, and side views of new miner's cap lamp.

TITLE OF PAPER: UMWA/BCOA/MSHA Mine
Illumination Survey

AUTHOR: Mr. Glenn Beckett
United Mine Workers of America
Charleston, West Virginia

Mr. Beckett currently serves as Chief Electrical Inspector for the United Mine Workers of America Safety Division International, Bridgeport, West Virginia. Prior to his present position, he was employed in the coal industry for 21 years as an electrician and mechanic. He worked two years as motor mechanic and leader in the General Electric rebuild shop, and was a mining and mine maintenance instructor for two years at Boone Career Center, Boone County, Danville, West Virginia.

Mr. Beckett serves on the Joint Industry Health and Safety Committee, the CIE TC-4.10 Mine Lighting Committee, the Ad Hoc Subcommittee of the IEEE for mine-related subjects, and the Advisory Committee for the VPI Annual Institute on Coal Mine Health, Safety and Research.

UMWA/BCOA/MSHA MINE ILLUMINATION SURVEY

by

Glenn Beckett[1]

ABSTRACT

Regulations requiring the illumination of working places in underground coal mines (CFR 30, 75.1719) became effective July 1, 1978. In April 1979, ten months had elapsed since the effective date, and a number of complaints concerning illumination were being directed to UMWA and BCOA officials.

With the cooperation of MSHA, a Joint Industry Health and Safety Committee was appointed to conduct a survey to solicit comments and suggestions from equipment operators and other mine personnel in order to identify any problems associated with mine illumination systems. The Committee consisted of one UMWA representative, one BCOA representative, and three MSHA representatives.

Two surveys were conducted--the first represented a cross-section of continuous miner and longwall sections in coal seams above 42 inches presently in use in the coal industry, and the second continued to cover specific problem areas such as low coal (seams below 42 inches), conventional equipment sections, direct-current power supplies, battery-powered scoops, and auger miners.

The committee found that improved lighting in working places is proving to be beneficial, and resulting in improvement of the safety of the miners. It should result in an increase in efficiency of mining operations. A great number of problems remain to be solved, but are not insurmountable.

Work for improved lighting is continuing by the committee in cooperation with USBM to help solve these problems.

It is the consensus of this committee that "with the cooperation of all parties concerned" other problem areas should be surveyed, and that the health and safety of all miners can be greatly improved.

INTRODUCTION

Regulations requiring the illumination of working places in underground coal mines (CFR 30, 75.1919) became effective July 1, 1978. In April, ten months had elapsed since the effective date and a number of complaints concerning illumination were being directed to UMWA and BCOA officials.

The Joint Industry Health and Safety Committee, with the cooperation of MSHA, appointed a committee to conduct a survey to solicit comments and suggestions from equipment operators and other mine personnel in order to identify any problems associated with mine illumination systems.

---

[1] Chief Electrical Inspector, United Mine Workers of America, Charleston, WV

The Committee consisted of one UMWA representative (Glenn Beckett, Chief Electrical Inspector), one BCOA representative, (Randolph Slone, Electrical Engineer, Eastern Operations Staff, Westmoreland Coal Company), and MSHA representatives (Cecil Lester, Coal Mine Specialist, CMS&H; and Robert Peluso, Chief, Special Projects, Technical Support), and Ralph Rhinehart, Chief, Beckley Electrical Testing Laboratory.

The illumination systems included in the first survey represented a cross-section of continuous miner and longwall sections in coal seams above 42 inches presently in use in the coal industry. The second survey continued to cover specific problem areas such as low coal (seams below 42 inches), conventional equipment sections, direct-current power supplies, battery-powered scoops, and auger miners.

SURVEY METHOD

The survey consisted of two parts. The first part dealt with observing the illumination systems and comparing the system with the approved STE configuration. The second part was a series of questions that was asked of each miner who operates the equipment or works around the illumination system.

Prior to the Committee arriving at the mine, each company was asked to make available to each member of the Committee a copy of the approved STE. In most instances, light measurements were made with a Go, No-Go meter during the discussions about the STE.

After the illumination system was compared to the STE, miners were individually asked questions about their experience with the illumination systems. A questionnaire was prepared by the UMWA and BCOA representatives to guide the questioning part. Some of the questions asked were as follows:

1. What was your first impression when you saw the lights?

2. What is your opinion of the lighting system now?

3. How long did it take for you to get used to the lights?

4. How long does it take for your eyes to adjust when you leave the illuminated area?

5. How long have you worked around the lights?

6. Do any of the lights bother you?

7. Do you have any recommendations for improvements?

Also, discussions were conducted with mine officials and safety committeemen of the UMWA, who accompanied the delegation during the mine visit. These discussions followed no specific format and only dealt with the general experience of installing the illumination systems and miners' acceptance.

DISCUSSION OF FINDINGS

During the survey, eighteen (18) continuous miner sections and one (1) longwall unit at eleven (11) mines in five (5) states were visited, and the seam heights varied from 42 inches to 9 feet. Illumination system installed on thirty-six (36) machines (not including shuttle cars and longwall) were observed and questions were asked of one hundred and two (102) miners.

Approximately seven percent (7%) of the miners interviewed wanted the illumination systems removed and ninety-three percent (93%) did not want the lights removed. Fifteen percent (15%) had no complaints with the systems provided and wanted no changes. In general, the majority (78%) of the miners interviewed, while expressing a favorable acceptance of the illumination systems provided, identified problem areas.

Problem lights were usually located very close to the work area of the miners and the problem areas will be discussed.

Continuous Miners

1. Light located on/in canopy - extreme glare to operator, helper and shuttle car operator and an obstruction to operator.
2. Light located immediately inby operator's position - obstructs operator's vision and creates glare for both operator and helper.
3. Not enough light on face - cannot see cutter head.
4. Lights located on offside of miner - direct view of operator and glare to shuttle car operator.
5. Light located in floor of operator's deck - obstruction to operator and glare to operator and helper.

Roof Bolting Machines

1. Light located on drill canopy - glare and insufficient light on hole being drilled.
2. Lights located adjacent to tool trays - extreme glare and obstruction.
3. Lights located on tramming canopy - extreme glare and obstruction.
4. Lights located immediately outby tramming deck - glare when tramming.
5. Lights located on TRS boom - glare.

Pick-up Loading Machines

1. Light located behind operator - glare when loading shuttle cars.

2. Light located on canopy - glare to operator.
3. Insufficient light in front of loader.

Shuttle Cars

1. Insufficient light.
2. Lights covered up or improperly oriented.

In many instances the problem lights were either covered or painted. When these situations were encountered and other problems were identified and lights were not covered, discussions with the miners were directed toward what recommendations they had to minimize the problem and many constructive ideas were presented by the miners. The miners usually recommended additional shielding, additional diffusing, less intensity, or relocating. (Often the recommendation was "remove the light"; but when the miners were questioned about the benefit of having lights in those areas, most indicated that the lights did help them to see better the surroundings of the machine if the glare could be minimized. Most miners stated that the lights did improve their peripheral vision and they didn't have to spot their cap lamp to see the surroundings.

The continuous miner operators and helpers expressed that the illumination provided helped them to see the roof, face, and ribs better. They also stated they were better able to observe their trailing cable and other personnel in the immediate work area. Roof bolter operators expressed that they were better able to see their surroundings, to observe the top and the hole being drilled. Shuttle car operators stated the illumination helps them to position their car when being loaded and to watch the top better.

The most positive comments received on illumination were on the one longwall unit we observed. The miners expressed a very favorable acceptance of the illumination provided with only minor complaints concerning the location of the fixtures.

Although, in general, the illumination systems were well received by the miners, approximately 85 percent of the illumination systems observed contained problem areas that generated complaints from the equipment operators or helpers. The majority of these complaints were caused by visual impedance (discomfort glare, disability glare, veilings, and after images) from light sources. Obtaining the required light levels is usually not a problem; obtaining it without discomfort glare is a problem. Discomfort glare is a difficult problem because it is very subjective. It does not affect all individuals to the same extent, and so far it has not been amendable to a simple measurement.

In almost all cases when discomfort glare was encountered, the cause was poorly designed and/or installed light fixtures. The light fixtures were placed in direct view of the machine operator and/or helper, did not contain proper diffusing materials, or shielding techniques were not properly utilized. The majority of these problems can be resolved by modification of the Statements of Test and Evaluation, utilizing the procedure outlined in the Administrator's for Coal Mine Safety and Health memorandum of March 5, 1979.

In 76 percent of the illumination systems observed, the STE was not being totally complied with. Failure to comply with the STE usually dealt with location of lights, angle of lights, lights covered or painted, lights very dirty, lights not burning, or lights not installed.

During the survey, mine management and maintenance personnel interviewed expressed dissatisfaction with the types of luminaries and installation drawings provided by the illumination manufacturers. Many stated that the fixtures provided were of "Mickey-Mouse" design and were not "mine duty" and lacked adequate mechanical protection and glare suppression.

The placement of lights on machines is a difficult task because of retrofitting rather than designing the lights as an integral part of the machine. While illumination manufacturers provided installation drawings, these drawings only show general arrangements of the machine and call for exact locations for fixtures. When these fixtures are installed according to these drawings, many are placed in areas unacceptable to the equipment operator or vulnerable to mechanical damage. These personnel also stated that equipment manufacturers were not providing equipment with illumination systems adequately installed as an integral part of the machine.

From our observations made in mines in coal seams greater than 42-inch thickness, the technology exists to provide the required levels of illumination in a manner acceptable to most miners; however, there is a definite need for improved diffusers, better shielding techniques, small low glare luminaires for critical areas, better system designs, improved installations, and increased knowledge of illumination techniques.

Fourteen (14) sections at eleven (11) mines in three (3) states were visited, and the seam heights varied from 26 inches to 42 inches. Illumination systems installed on twenty-four (24) machines (not including shuttle cars) were observed and questions were asked of fifty-seven (57) miners.

Approximately sixty-three percent (63%) of the miners interviewed wanted the illumination systems removed and thirty-seven percent (37%) did not want the lights removed. Ten percent (10%) had no complaints with the systems provided and wanted no changes. Twenty-seven percent (27%) expressed a favorable acceptance of the overall lighting provided but recommended changes to alleviate problem areas. The number of dissatisfied miners that operate or work in proximity to equipment with lighting systems clearly attests to the fact that the problems of complying with the illumination regulations in an acceptable manner are much more difficult in seams less than 42 inches in thickness.

Much of the dissatisfaction was generated by glare problems created by inadequate light fixtures, improper lighting system design, and poor installation and maintenance. Industry personnel display an amazing lack of knowledge regarding lighting technology, available lighting equipment and the technical requirements of the regulations. Many responsible personnel stated that they had never seen or heard of the Administrator's policy memorandum outlining MSHA policy regarding illumination regulations and the procedure for modification of Statements of Test and Evaluation.

In many instances the miners refused to operate the lights long enough to become accustomed to them and stated that they only turned the lights on when an inspector or supervisor was present. Very few of the systems were installed in conformity to the STE, and coal dust and grease were allowed to accumulate on many of the light fixtures to the extent that very little light was being provided. The committee observed lights not burning, lights covered, and areas where the light fixture had been removed. Also, in many instances, no effort was made to place the light source out of the machine operator's direct vision, forcing the operator to gaze continually into a bright light source. Several systems observed were connected in such a manner that the lights only burned when the machine pump motor was running. This continual changing from dark to light to dark is very annoying and is not acceptable to the miners.

Another important cause of discomfort glare which was responsible for so many negative comments from miners is the fact that most of the currently available light fixtures are totally unsuitable for use in many of the critical areas where light fixtures must be installed in a miner's direct field of vision. These fixtures were manufactured with a minimum of optical engineering and with little regard for the basic techniques of light transmission and distribution. Once a light fixture is developed to a barely marketable state, very little or no research effort has been devoted to improvement or correction of apparent deficiencies.

Working places are normally driven wider in thin coal seams than in the thicker seams. The Committee observed working places with widths as great as 30 feet during this survey. The widest working places observed during the survey of seams above 42 inches were 20 feet. Mining machine frames are normally 8 to 9 feet in width regardless of seam height. Therefore, to illuminate the rib in this coal seams, the light must be transmitted a greater distance horizontally. Since a basic law of physics states that light diminishes as the square of the distance, light sources of more than three times the intensity are required to illuminate the coal rib in thin coal seams. The miner normally works on his hands and knees and the light fixtures of necessity are installed at eye level, which compounds the glare problem.

Another deterrent to the overall effort to provide proper illumination of working places is and has been the reluctance of original equipment manufacturers to include facilities for lighting in new equipment design. New machines are being delivered to coal mines daily that are not equipped with lighting systems, and the mine operator is forced to retrofit the new machine and install the required lighting equipment. Often there is absolutely no available space for installation of the lighting equipment. This results in light fixtures and power supply compartments being installed in the operator's compartment and on the side of machines where they are vulnerable to mechanical damage and can create a hazardous condition to the equipment operator.

Auger-type continuous mining machines and bottom coal cutting machines that are prepelled by wire ropes present special illumination problems. It is necessary to set metal jack pipes near the face for anchoring the wire ropes that are used to propel these machines. Light fixtures installed on these machines shine directly into the face of jacksetters and machine helpers while they are setting these jacks. Also, jacksetters and machine helpers signal to the machine operator by means of their cap lamps when it is necessary to tighten or release the ropes during routine operation of the machine. All the illumination systems developed to date for these machines have interferred with the miner's ability to signal to each other. Also, the jacksetters crawl around the machine with light fixtures installed at eye level and glare is created. Several fatal accidents have occurred on these machines when jacksetters are caught in the rotating bits on these machines; therefore, in such a dangerous situation, even a small amount of glare is not acceptable.

RECOMMENDATIONS

If the expected benefits in safety, health, and efficiency are ever realized from the illumination effort, the joint cooperation of labor, industry, and government is absolutely essential. The majority of miners' complaints regarding illumination of working places can be resolved by industry, labor, MSHA, and equipment manufacturers and suppliers adherence to the following recommendations.

Industry

1. Do not install lights inside operator's positions, under canopies, or other locations that interfere with entrance to or exit from the operator's deck.

2. Whenever practical, locate or shield light sources so that they are not in the machine operator's direct field of vision. Where it is necessary to place light sources in a miner's field of vision, proper diffusing or guarding should be used to reduce discomfort glare to an acceptable level. Never place bare, undiffused light sources, except headlights operating in the direction of travel, (i.e., headlights on continuous miners, loading machines, scoops, etc.) in the direct view of miners.

3. Whenever practicable, install lighting systems in accordance with the STE. When a light fixture installed in accordance with the STE created glare or other visibility problems for miners, obstructs entrance to or exit from operators' compartments, or creates maintenance problems, place the light fixture in the optimum location and request modification of the STE in accordance with the Administrator's for Coal Mine Safety and Health memorandum of August 2, 1979. Future installation of lighting systems on similar equipment

operating under similar mining conditions should be made in accordance with the modified STE.

4. Maintain light fixtures free from accumulations of coal dust, dirt or other contaminants and in safe operating condition.

5. Do not wire lighting systems into the machine electric circuitry in such manner that will cause the lights to go on and off as the hydraulic pump motor is started and stopped. The lights should burn at all times the machine is energized in the working place.

6. Listen objectively to miners' complaints. Correct those complaints in accordance with the above recommendations and then insist that the light be left on at all times the machine is energized in the working place.

7. Prior to purchasing lighting equipment, industry officials should carefully evaluate available hardware and purchase lighting equipment that is suitable for the mining conditions found in each mine. There are lighting systems being marketed that are practically impossible to maintain and are unsuitable for use in certain mining conditions and unacceptable to miners.

8. The interior of cabs and canopies, except control levers and switches, should be painted with flat black paint to minimize reflected glare. Guards over lens should also be painted with flat black paint.

Labor

1. Keep lights clean on your machine.

2. Report promptly any lights not burning.

3. If a particular light blocks your vision or creates discomfort glare, do not paint the lens or cover the light fixture, which destroys the permissibility of the machine, but report it to your supervisor and request corrective action.

4. Keep lights turned on at all times the machine is energized in the working place.

5. Feel free to make any recommendations for improvement of lighting systems to industry officials, labor officials, or MSHA officials. Every recommendation shall receive prompt consideration.

MSHA

1. Heatlights on continuous mining machines and loading machines should be oriented so that the maximum amount of light is provided on the

coal face. This improves the contrast ratio and improves the ability of the machine operator to see the location of the cutting bits or gathering arms. Therefore, to allow the most efficient utilization of the available light, light measurements should not be taken of the floor area between the cutter boom hinge pin or gathering head hinge pin and the coal face.

2. Light fixtures installed adjacent to supply trays on dual-head roof bolting machines create objectionable glare to the operator and helper. Therefore, to allow removal or repositioning of these light fixtures, the lighting system should be considered to be in compliance if the required level of light is provided as determined by illumination measurements made with the drill heads either together or separated approximately 8 feet and in position to drill holes or install roof bolts.

3. In coal seams under 42 inches in thickness, hazards to miners from falls of rib or face or stumbling hazards are practically nonexistant. In thin seams, the glare problem is much worse than in thicker seams. One obvious method of decreasing discomfort glare is to reduce light intensity. Experience with roof bolting machines has shown that illumination of the area 5 feet in all directions from the machine is adequate in thin coal seams. This is supported by the fact that a greater percentage of roof bolting machine operators and helpers found the lights to be acceptable and made positive comments. Therefore, the area to be illuminated for continuous miners, coal drills, cutting machines, and loading machines should be changed to include an area of 5 feet from each side of the machine. This change would allow additional diffusers to be installed on existing light fixtures to reduce the glare.

4. In coal seams less than 42 inches in thickness, the area required to be illuminated by remotely controlled continuous miners should be changed to exclude the area of the right side of the working place extending a distance of the outby one half of the main frame shown in Appendix V until glare-free light fixtures are made available.

5. In coal seams less than 42 inches in thickness, measurements should not be taken of the area in front of and to the side of the roof bolting machine operator until glare-free light fixtures are developed suitable for lighting this critical area.

6. In all coal seams, regardless of height, all scoops being used as load-haul-dump vehicles, clean-up scoops, or supply vehicles should be illuminated in accordance with Section 75.1719-1(e) (6) while such vehicles are being operated in the working place. Furthermore, to provide for the maximum utilization of the available light, when the height of the coal does not permit installation of light fixtures on top of these vehicles, the areas required to be illuminated the same as higher coal.

Tests conducted by the UMWA/BCOA/MSHA illumination committee in the No. 1 Mine, Coal X, Incorporated, Christian, Logan County, West Virginia, have shown conclusively that load-haul-dump vehicles and other battery-powered scoops illuminated either in compliance with Section 75.1719-1(e) (6) or the same as shuttle cars.

7. Because of the hazards created by current lighting systems, the illumination standards should not be enforced for a rope-propelled, auger-type continuous miners and bottom cutting machines for a period of 12 months to allow the Bureau of Mines time to conduct research toward developing a safe, glare-free system acceptable to miners.

8. Sufficient research funds should be made available by the Bureau of Mines for the rapid development of glare-free light fixtures for critical areas. There is a definite need for an immediate crash research program to develop low-glare light fixtures for these critical areas.

9. Federal mine inspectors should insist that light fixtures be installed and maintained in accordance with the STE; however, when the inspector observes a lighting system that is not installed in compliance with the STE, the inspector should explain the STE modification procedure to the mine operator and offer MSHA assistance in modifying the STE.

10. A meeting of light fixture manufacturers and mining equipment manufacturers should be held in the near future for the purpose of allowing the committee an opportunity to discuss their findings during the survey and the deficiencies in current design of lighting systems.

11. A series of seminars for the distribution of information regarding available illumination technology and equipment should be held at strategic locations in the various coal-producing regions. Chief electricians, electrical engineers, maintenance foremen, electricians, mechanics, and other industry personnel directly involved in installation and maintenance of lighting hardware should be invited and encouraged to attend.

12. Technical Support should require more stringent glare controls in critical areas when considering applications for Statements of Test and Evaluation.

13. MSHA should explore methods for prohibiting delivery of new, used, or rebuilt electric face equipment to coal mines unless means for compliance with Section 75.1719 is provided.

14. MSHA district managers should forward a copy of all modifications of Statements of Test and Evaluation to the lighting equipment manu-

facturer so that these changes may be incorporated into future lighting system design.

Equipment Manufacturers and Suppliers

1. Manufacturers and used equipment dealers should not ship machines to coal mines unless provisions are made for compliance with the illumination regulations. Design of new machines and rebuilding of existing machines should include provisions for installation of light fixtures in recessed areas or other protected locations.

2. Persons designing lighting systems should concentrate their efforts on making systems more glare free.

3. The interiors of cabs and canopies of new and rebuilt equipment, except control levers and switches, should be painted with flat black paint to minimize discomfort glare. Guards over light lens should also be painted with flat black paint.

4. The services of qualified physicists, optical experts, and illumination engineers should be obtained and used in the design of light fixtures.

The committee has found that improved lighting in working places is proving to be beneficial and resulting in improvement of the safety of the miners and should result in an increase in efficiency of mining operations. A great number of problems remain to be solved but are not insurmountable.

Work for improved lighting is continuing by the committee in cooperation with USBM to help solve these problems.

It is the consensus of this committee that "with the cooperation of all parties concerned" other problem areas should be surveyed, and that the health and safety of all miners can be greatly improved.

TITLE OF PAPER: Overview of U.S. Bureau of Mines
Illumination Research Program

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He has held a number of technical and management positions in private industry involving product development in areas of laboratory instrumentation and consumer products. Prior to joining the Bureau, he held the position of Director of Engineering at Radioear Corporation.

Mr. Lewis is a member of the American TC-4.10 Committee

OVERVIEW OF THE U.S. BUREAU OF MINES ILLUMINATION RESEARCH PROGRAM, 1981

by

William H. Lewis[1]

ABSTRACT

Since the passage of the Coal Mine Health and Safety Acts of 1969 and 1977, the U.S. Bureau of Mines has undertaken a major research effort in the area of mine lighting. This paper will attempt to give an overview of the research efforts to date, its present state and anticipated future efforts in the following three major areas:

- Underground Coal Mine Illumination
- Surface Mine Illumination
- Underground Metal and Nonmetal Mine Illumination

INTRODUCTION

> "the eye has always been held the choicest gift of nature - the most marvelous product of her plastic force ... dwell on its penetrating power, on the swiftness of succession of its brilliant pictures, and on the riches it spreads before our sense"
>
> Helmholtz

Why Mine Lighting?

Depending on the audience, one could answer the question with a question as Socrates might have done. Why do we light our factories, our schools, our hospitals, our homes, our streets? The need for light in our environment is obvious. Of all of our senses, vision is the most remarkable and informative. It is estimated that 80 percent of all human knowledge has been acquired through man's sense of vision and is our primary source of sensually perceived data and environmental awareness.

What Are the Benefits?

If man's primary sense (vision) is impaired for whatever reason, either by disfunction of the eye itself or by a lack of adequate illumination, man cannot function to his fullest potential. The benefits of enhancing this

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sense are self-evident, increased safety and productivity. In the words of Roger Bacon, "He that cannot see well, let him go softly. What the eye has seen, the hand may do."

Safety professionals recognize that adequate illumination is essential to a safe and productive work environment in industrial settings. The need for adequate illumination in underground coal mines is even greater. Congress recognized this essential need in the Coal Mine Health and Safety Acts of 1969 and 1977 and charged the Secretary of the Interior with the responsibility and the authority for developing and prescribing minimum illumination standards for mining environments. Since the passage of the "Acts," the Bureau of Mines has undertaken a major research effort to bring better lighting systems and technology to the mining industry.

Today, 85 percent of all required underground coal mining machinery is equipped with an approved lighting system and represents one of the most evolutionary changes to the mining environment in the last decade.

PROGRAM STRUCTURE AND OBJECTIVES

The present mine illumination research program is divided into three major areas:

- Underground Coal Mine Illumination Research
- Surface Mine Illumination Research
- Underground Metal and Nonmetal Mine Illumination Research

The primary objective of the program is to reduce accidents and injuries and improve safety in the working environment of miners through the use of improved lighting technology.

Recent emphasis of the program focuses on six major efforts:

- Illumination System Hardware Development
- Basic Studies
- Demonstration of Underground Coal Mine Illumination Systems
- Factory Integration of Illumination Systems into Mining Machinery
- Feasibility Studies of the Proposed Surface Mine Illumination Standards
- Illumination Standards Development for Underground Metal and Nonmetal Mines

ILLUMINATION SYSTEM HARDWARE DEVELOPMENT

This program is an on-going effort involving the development of new and improved lighting systems and related equipment for use in mining environments. Present efforts focus on the development of (1) an improved miner's caplamp and battery and (2) low glare machine mounted lighting systems for thin seam coal mine applications.

Miners Caplamp Development

The present day miner's caplamp and battery system has for many years proven to be a highly reliable and indispensable aid to miners and has undergone few changes in its many years of existence. Recent developments in battery technology, however, have made additional improvements possible. Over the past two years, Energy Research Corporation, under contract to the Bureau of Mines, has been developing a new caplamp battery. The new battery (Fig. 1) is based on nickel cadmium technology and features significant reductions in weight and size as compared to the conventional lead acid battery. Among the more significant improvements are a 48 percent reduction in weight and a 15 percent reduction in volume. Cycle life has also been increased and is expected to be in the range of 1000 charging cycles as compared to 400 for the lead acid battery. The battery has been designed to be compatible with existing charging systems and caplamps, which illuminates the need to replace this equipment when phasing in the new batteries.

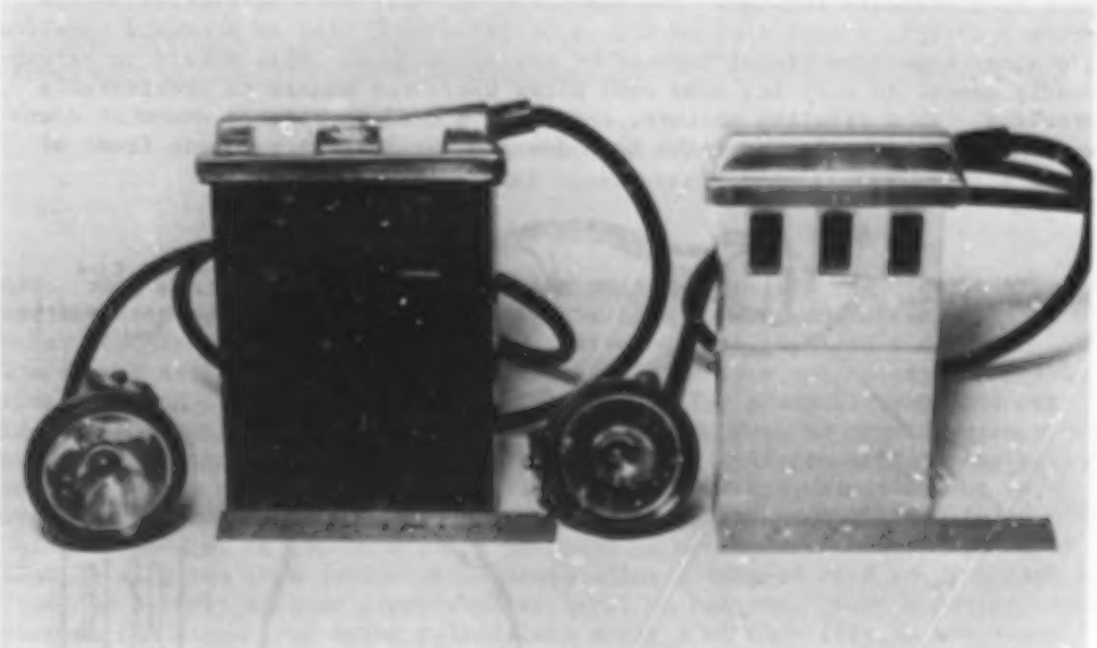

FIGURE 1. - Prototype nickel cadmium battery (right).
Conventional lead acid battery (left).

TABLE 1. - Comparative Battery Specification

Specification	Nickel Cadmium	Lead Acid
Weight (lbs)...............	2.42	4.66
Average Voltage............	3.5	3.7
Capacity (ah)..............	15.0	12.0
Energy (wh)................	52.0	44.0
Energy Density (wh/lb).....	21.4	9.5
Volume (in^3)...............	46.1	53.4
Cycle Life.................	1000	400
Cost (20,000 u/yr).........	$50	$30

To enhance the overall marketability of the new caplamp system, additional features (Fig. 2) are being incorporated into the design. A new reflector has been designed to accept the tungsten halogen type bulb shown in Fig. 3. The new bulb will offer the equivalent light output of the conventional incandescent bulb, but with reduced power consumption and greater life expectancy. Because the new bulb has only one filament, two bulbs will be used as a failsafe feature. The headpiece assembly will be similar to the present design, except that an elevation adjustment will be provided to allow the miner some directional control of the light beam. This should be particularly useful in very low seam coal mines where the miners do considerable crawling. In a crawling posture, the miner's head is pointed somewhat downward and consequently the light beam does not project very far in front of

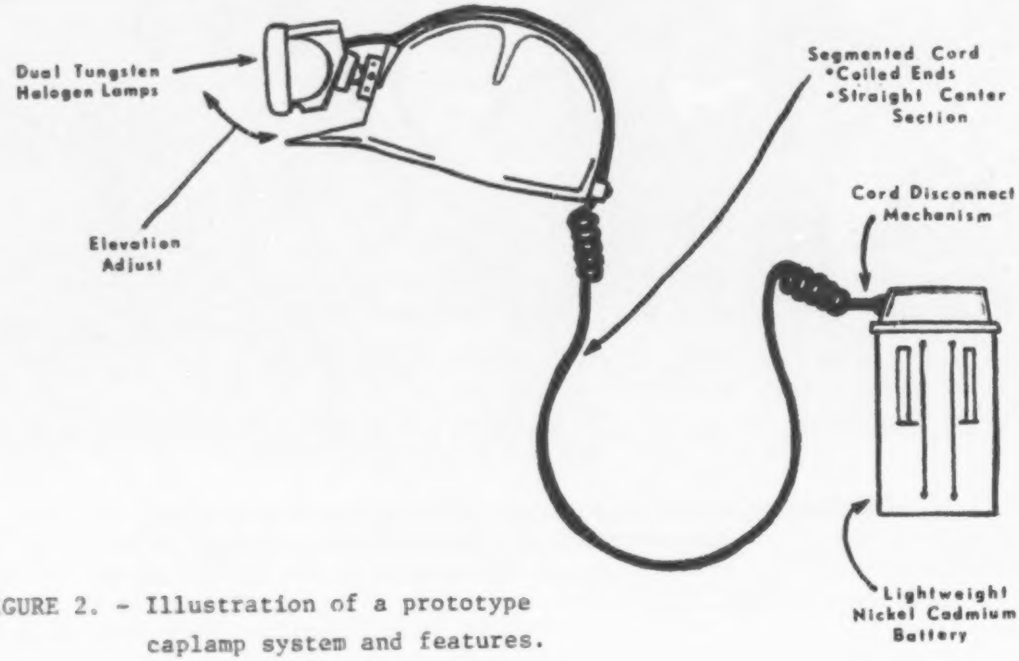
Dual Tungsten Halogen Lamps
Elevation Adjust
Segmented Cord
•Coiled Ends
•Straight Center Section
Cord Disconnect Mechanism
Lightweight Nickel Cadmium Battery

FIGURE 2. - Illustration of a prototype caplamp system and features.

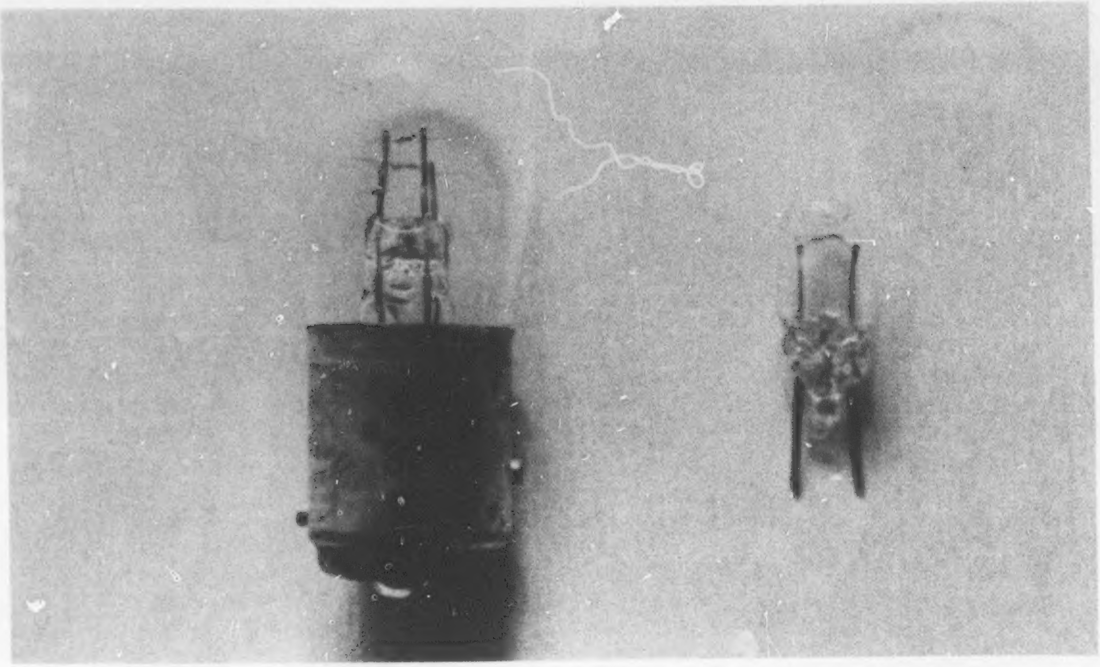

FIGURE 3. - Tungsten halogen lamp (right).
Conventional incandescent lamp (left).

him. With the elevation adjustment, the miner can adjust the beam to project farther in front without repositioning his head to an uncomfortable position. Other features being considered are a coiled battery cord and a cord-disconnect mechanism. Human factor studies of battery cord designs suggest that a coiled cord may provide greater safety. The presently supplied cap-lamp cord comes in one standard length, which when worn by shorter miners has a tendency to bow out away from the body (Fig. 4). In comparison, the coiled cord design is more adaptable to variations in body dimensions and has a tendency to lay closer to the body, which reduces the probability of the cord being snagged or caught in a piece of rotating machinery. Consideration is also being given to a device which would allow a snagged cord to disengage from the battery at some predetermined level of tension. Such a device could prevent the miner from being pulled into a piece of machinery in the event the cord became entangled. Although preliminary studies suggest these features are beneficial, cost considerations and field studies will ultimately determine whether they will be incorporated into the final product.

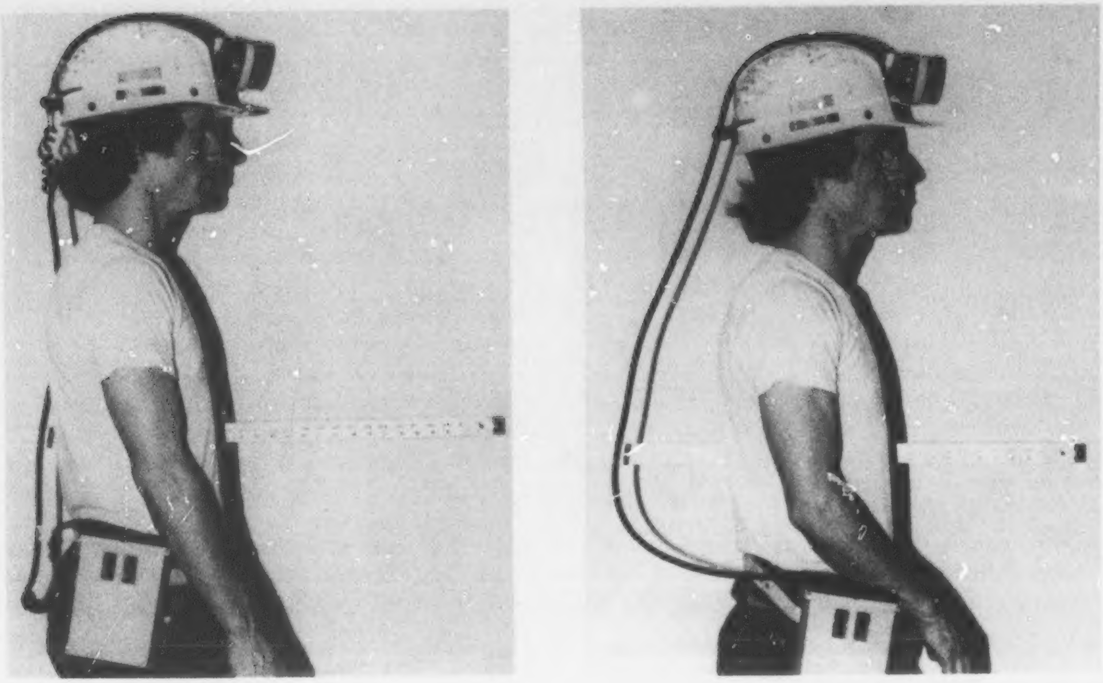

FIGURE 4. - Body conformity of coiled cord configuration (left). Standard cord (right).

Low Glare Illumination Systems

Conceptually, the notion of providing illumination in underground coal mines appears simple, but in practice, its implementation is filled with subtle and complex problems. A recent survey[1] conducted by the UMWA/BCOA Joint Industry Health and Safety Committee reported on problems and worker complaints of illumination systems installed in underground coal mines. Most of the complaints related to the problem of vision impedance (discomfort glare, disability glare, veiling reflections and after images) caused by the light sources. To address this problem, the Bureau has undertaken a number of projects to develop low glare illumination systems, particularly for use in thin seam coal mine applications where glare problems are more prevalent.

Recent efforts in this area have led to the development of the first of a series of prototype low glare illumination systems (Fig. 5). The new fluorescent lighting system is small in size and can be mounted vertically with as little as 13 inches of vertical mounting space. The luminaires' small size and vertical mounting capability allow the lighting designer to make

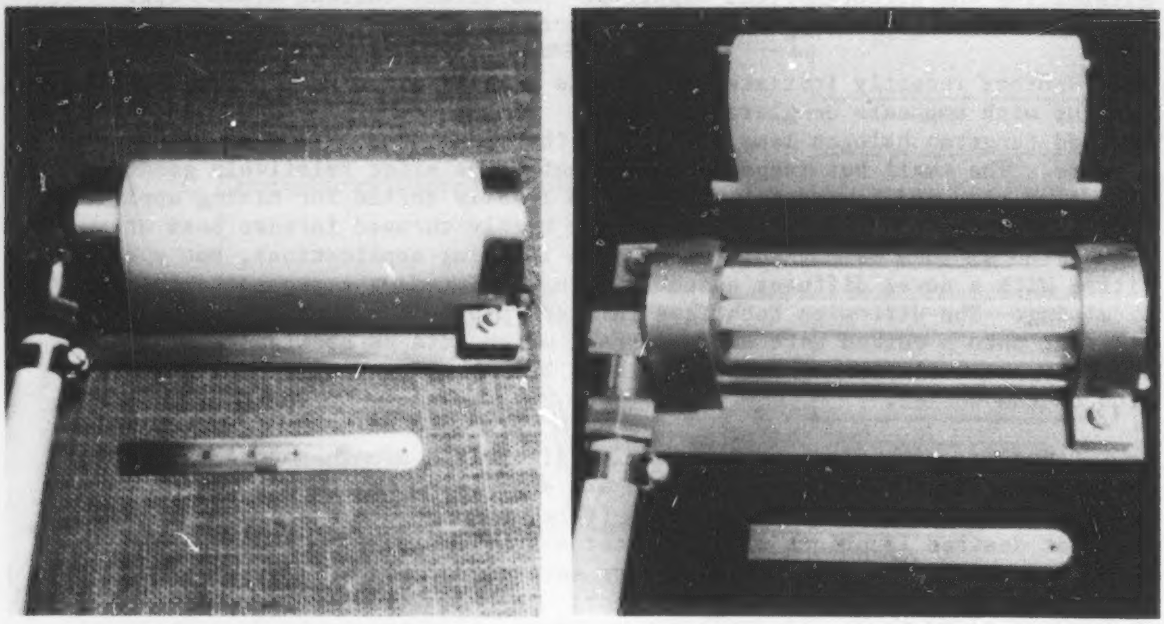

FIGURE 5. - Prototype low glare lighting system (left).
Diffuser/guard removed (right).

better use of the light distribution pattern of cylindrically shaped fixtures. The fixture has been designed to accommodate a number of lamp modules which can house 1, 2, or 3 fluorescent lamps and gives the lighting designer some flexibility in selecting the light output. Each lamp module which contains its own reflector can easily be interchanged in the fixture. The lightweight compact fixture measures only 12-1/2 x 3 x 4 inches. Power is supplied through a 90 degree packing gland which conserves vertical mounting space. The experimental packing gland has been designed for "quick disconnect" to facilitate maintenance and fixture replacement. To reduce glare, the fixture has a unique snap on white translucent plastic diffuser which acts as a guard and reduces the source brightness by spreading the light over a larger surface area. The diffuser/guard can be readily removed for cleaning, or replaced without tools, and does not affect the explosion proof integrity of the fixture. Prototype systems are being designed to function from both alternating and direct current supplies. The direct current system will function directly from a 300 VDC power source without an inverter ballast.

Another recently initiated program is investigating more novel fixture designs with emphasis on glare reduction. One system utilizes a small prefocused tungsten halogen lamp similar to the ones commonly used in slide projectors. The small but rugged incandescent lamps offer relatively good operating life and low cost; making them ideally suited for mining applications. The light output of the lamp is a highly focused intense beam of light, and as such is not suited for area lighting applications, but when fitted with a novel diffuser assembly being explored; the prospects look promising. The diffusion technique involves projecting the intense beam of light onto a curved matt white surface which acts as a diffuser and secondary source; the main source (lamp) being kept out of the field of view of the worker.

Concepts using fibre optics to pipe light from a main source or sources to various locations around a machine are also being explored. The narrow beam of light transmitted through the fibre optic cables would then be terminated at desired locations with diffuser assemblies similar to the ones described above. This technique offers several advantages over present lighting systems in both safety and cost; in that fewer explosion proof enclosures would be required and fewer elecrical cables would be routed around the machine. The diffuser assemblies which terminate the fibre optics cables need not be explosion proof and can be made more inexpensively.

Packaging concepts for fluorescent lamps are also being investigated that have a very low profile and rectangular in shape. The design will use several fluorescent lamps of low wattage and brightness and will take advantage of the larger surface area of the rectangular shape to diffuse the light more effectively. These luminaires are contemplated to have application on longwalls as well as conventional and continuous mining machinery.

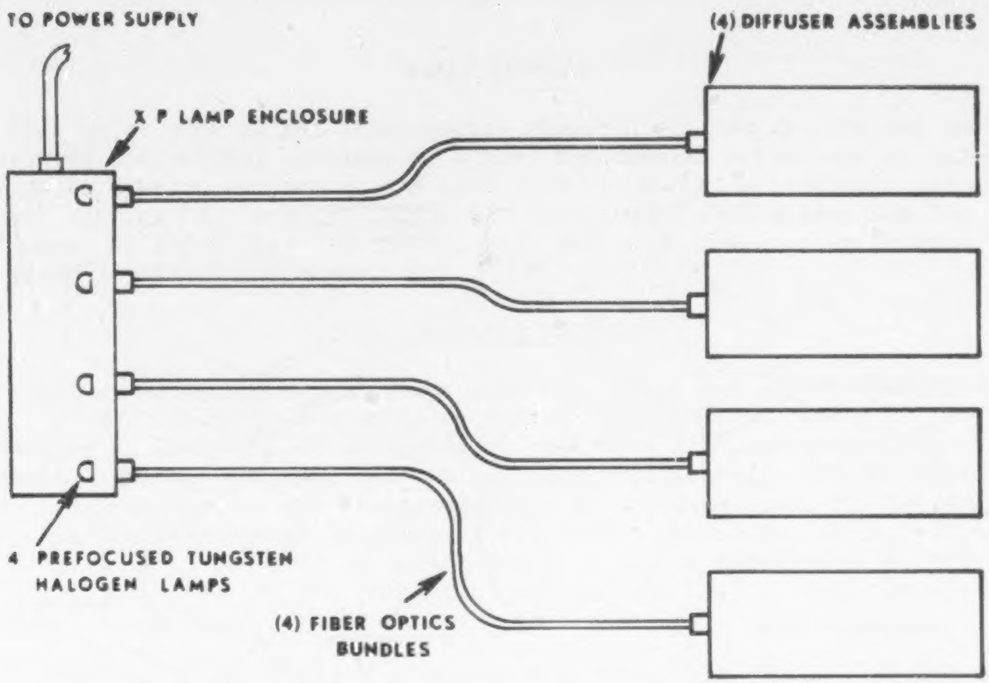
TO POWER SUPPLY
(4) DIFFUSER ASSEMBLIES
X P LAMP ENCLOSURE
4 PREFOCUSED TUNGSTEN HALOGEN LAMPS
(4) FIBER OPTICS BUNDLES

FIGURE 6. - Illustration of multiple source (incandescent) fiber optics lighting concept.

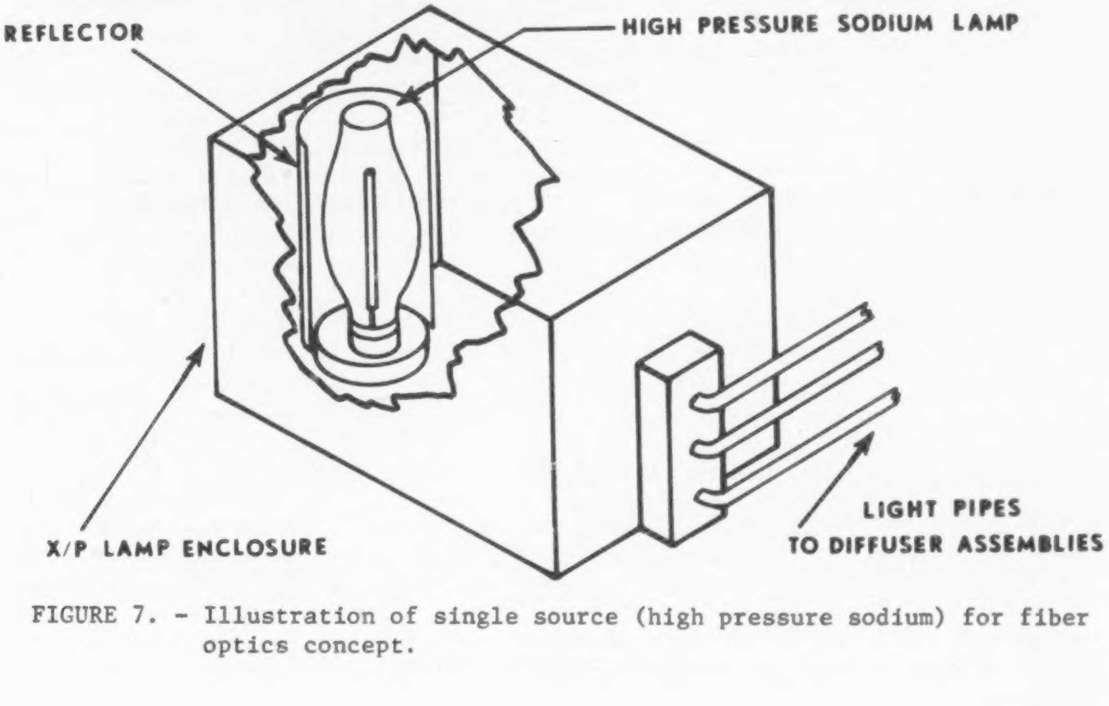
REFLECTOR
HIGH PRESSURE SODIUM LAMP
X/P LAMP ENCLOSURE
LIGHT PIPES
TO DIFFUSER ASSEMBLIES

FIGURE 7. - Illustration of single source (high pressure sodium) for fiber optics concept.

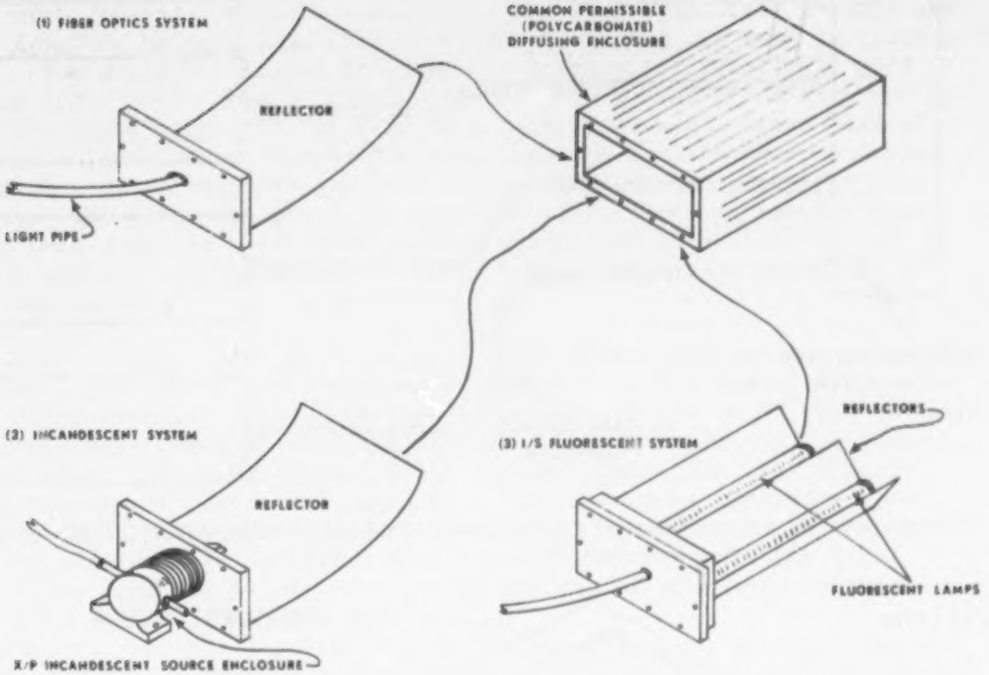
(1) FIBER OPTICS SYSTEM
REFLECTOR
LIGHT PIPE
COMMON PERMISSIBLE (POLYCARBONATE) DIFFUSING ENCLOSURE
(2) INCANDESCENT SYSTEM
REFLECTOR
X/P INCANDESCENT SOURCE ENCLOSURE
(3) I/S FLUORESCENT SYSTEM
REFLECTORS
FLUORESCENT LAMPS

FIGURE 8. - Illustration of fiber optics, incandescent and fluorescent lighting diffuser assemblies.

BASIC STUDIES

This major area in the illumination research program is oriented towards researching and solving problems of a more fundamental nature and includes programs to develop an underground coal mine illumination handbook; pyschophysical studies of glare in illuminated underground coal mines, and the development of guidelines for installation and maintenance of underground coal mine illumination systems.

Mine Lighting Handbook

Findings of the UMWA/BCOA Joint Industry Health and Safety Committee Survey of underground coal mine illumination reported that "industry personnel display an amazing lack of knowledge regarding lighting technology, available lighting equipment and the technical requirements of the regulations." In response to the recommendations of the committee, the Bureau has undertaken the development of a mine illumination handbook. The objective of this program is to provide the mining industry with a comprehensive, authoritative reference text on the subject of underground coal mine illumination. The major topics to be discussed in the text will be:

- Overview of the history of mine illumination and the development of federal lighting regulations
- Lighting fundamentals and optical principals
- Illumination regulations for underground coal mines
- Light sources and powering requirements
- Permissible fixture and enclosure design
- Light measuring theory and instrumentation
- Guidelines for installation and maintenance of mine illumination systems
- Design of machine mounted lighting systems
- Glare control and diffusing techniques
- Review of available hardware
- Photography in underground coal mines and permissiblity considerations

The format and style of the text will be written to accommodate readers with varying degrees of expertise and educational level and should be a valuable reference text for mine maintenance personnel as well as lighting engineers and equipment manufacturers.

Development of Maintenance Guidelines

The next program in this area was a study to determine the state of the art of mine illumination hardware, define lighting system installation and maintenance problems and assess personnel acceptance of lighting in underground coal mines. Longwall as well as mobile face machine illumination systems were addressed. The study included a survey of 60 mines, 11 lighting hardware manufacturers and 9 mobile face equipment manufacturers. Major problems that were identified in room and pillar installations include damage of exposed components, electrical failures and reduced lamp life with extreme variability among mining operations. Most longwall lighting installations had low to moderate maintenance requirements. Cable damage was found to be the most significant problem. Most mobile face equipment operators surveyed were in favor of the lighting systems on their machines, but many of them complained about glare problems. In contrast, longwall lighting systems were unanimously accepted by face personnel and the few complaints received about these systems were minor. Based on the survey, general installation and maintenance guidelines have been developed and should provide valuable assistance to lighting maintenance personnel in reducing maintenance costs and machine downtime associated with lighting system failures. A more detailed discussion of this Bureau program is discussed in a separate paper presented at these proceedings[7].

Glare Studies

Another program in this area is a study of glare problems in illuminated coal mine environments. This program is an outgrowth of recommendations of the UMWA/BCOA Joint Industry Health and Safety Committee survey. Studies to date have focused on determining the average glare tolerance of a representative sample of miners and a comparison of these tolerance levels with the levels of glare that the miners are typically experiencing from their machine illumination systems. Standard vision and discomfort glare tests have been performed on approximately 170 miners. In-mine data relating to discomfort and disability glare has also been taken on a number of different illuminated machines with a variety of different lighting systems. Results of this study have not been finalized at this time, but a detailed discussion of the test methodology and work accomplished to date is presented in separate papers by Messiers Guth[4] and Crouch[3] in these proceedings. The ultimate goal of this program is to provide a better understanding of the nature of glare problems in illuminated underground coal mine environments so that lighting system designers and manufacturers are better able to supply the mining industry with more acceptable and effective low glare lighting systems.

DEMONSTRATIONS OF UNDERGROUND COAL MINE ILLUMINATION SYSTEMS

Over the past several years, the Bureau of Mines has undertaken a program through contract research to assist the mining industry in complying with Federal Underground Coal Mine Regulations. Basically, the program has provided the expertise for designing, installing, and evaluating illumination systems in those areas which pose difficult or unique problems to the mining industry in implementing the regulations. Demonstrations have been completed on a large number of machine types and work areas including low and high seam longwalls, shortwalls, slope operations, and most conventional and continuous mining equipment.

The latest study that has been completed involved lighting system designs for 9 machines in four different mining locations. A list of machine types and pertinent information is given in Table 2. The overall objectives of this program were to:

- Determine the feasibility of illuminating low seam equipment
- Determine the reliability of 300 and 600 VDC illumination systems
- Minimize glare
- Stress mine worthy design
- Identify problems for future research

Results of the program have shown that with good engineering design, reliable mine worthy AC or DC illumination systems can be installed in a wide variety of seam conditions. In general, the systems were well received by the operators, but some complaints were made about glare and the loss of caplamp signaling ability. Mineworthy lighting designs were achievable, but a high degree of design effort and usually extensive machine modification is required. Material costs for the 9 machines varied from $2,222 to $5,550 with labor costs ranging from $2,500 to $9,375. The overall average cost per machine was $8,406 with a range of from $4,722 to $13,852.

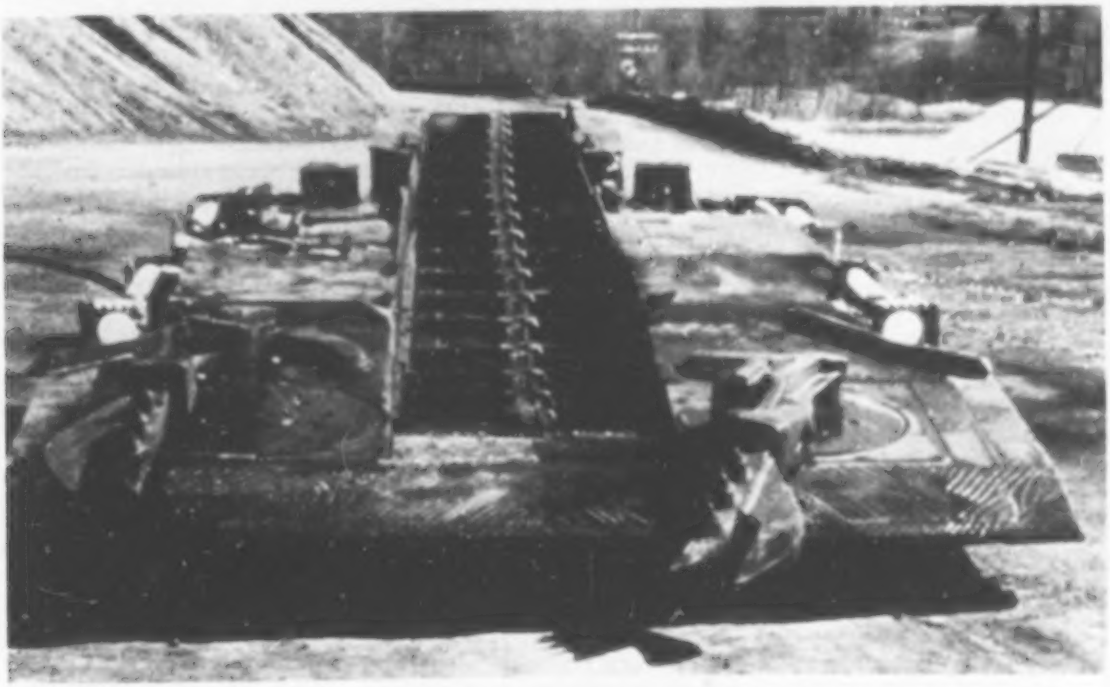

FIGURE 9. - Low seam Joy 14BU10 loader with installed lighting system.

TABLE 2. - Demonstrated Machines

Machine Type	Machine Height (in)	Seam Height (in)	Lighting System	Electrical System
Joy 14BU10.......... Loader	24	28 to 42	(4) Ocenco Fluorescent (2) Ocenco Headlamps	300VDC
Joy 12RB............ Cutting Machine	24	28 to 42	(6) Ocenco Fluorescent (4) Ocenco Headlamps	300VDC
Gallis 4100......... Face Drill	24	28 to 42	(5) Ocenco Fluorescent (2) Ocenco Headlamps	300VDC
Long Airdox......... Roof Bolter	24	28 to 42	(3) Ocenco Fluorescent (1) Control Products Mercury Vapor	300VDC
N.M.S. Marietta..... Continuous Miner	48	96	(3) Control Products Incandescent Headlamps (4) Control Products Fluorescent	550VDC
F.M.C. 320A......... Roof Bolter	60	96	(8) Control Products Fluorescent	330VDC
F.M.C. 320H......... Roof Bolter	96	144	(12) McJunkin Fluorescent	440VAC
Joy ICM-3B.......... Continuous Miner	60	90	(3) Ocenco Headlamps (5) Ocenco Fluorescent	550VDC
Joy 14BU10.......... Loader	48	90	(7) Ocenco Fluorescent	550VDC

FACTORY INTEGRATION OF ILLUMINATION SYSTEMS INTO MINING MACHINERY

Efforts in this area are directed towards stimulating mining equipment manufacturers to integrate illumination systems into their equipment at the factory. The objective of the program is twofold: (1) to relieve the mining companies from the burden of designing and retrofitting machine mounted illumination systems in the field and (2) provide better protection of the illumination systems from damage due to roof falls, collisions and in general to improve the overall reliability and structural integrity of the systems being supplied. To this end, the Bureau has undertaken numerous cooperative programs with mining equipment manufacturers; they include such companies as FMC Corp., J. H. Fletcher & Co., Long-Airdox Co., National Mine Service Co., and Fairchild Inc.

Although considerable success has been achieved in stimulating equipment manufacturers to supply factory equipped illumination systems on their machinery; the major objective of achieving truly integrated lighting systems has not been accomplished. A recent study performed under Bureau contract to assess the state of the art of factory supplied lighting systems reported that; all manufacturers of low seam roof bolters and continuous miners can currently supply MSHA approved lighting systems. Most of the manufacturers install lighting systems that have been designed by lighting suppliers. Equipment manufacturers are not supplying approved lighting systems on rope propelled bottom cutters or auger type continuous miners because of insufficient technology and the lack of adequate low glare illumination systems. The three main manufacturers of rope propelled bottom cutters are not actively developing lighting systems for this equipment, primarily because of a declining demand for their equipment and that higher priority projects are consuming the efforts of their relatively small engineering staffs. The sophistication of the equipment being supplied varies considerably from one manufacturer to another. Most equipment manufacturers are not interested in "Factory Integrated Lighting." They feel that the lighting systems would not be cost competitive when compared to "Factory Retrofit Systems." A truly integrated lighting system usually requires extensive redesign of the machine and represents a considerable investment in cost and engineering effort. Many of the equipment operators feel that factory integrated systems are not feasible because mine operators request particular types or brands of lighting systems which makes it difficult if not impossible to standardize their design. Others argue that integrating or recessing the lights into the machine superstructure necessitates more lights in the design because some peripheral lighting is lost from each of the luminaires when it is recessed. Development and tooling costs for new machines are expensive, which means standardized lighting designs are a "must." This is not always possible because of customer preferences for particular types or brands of lighting equipment. Some equipment manufacturers are concerned about future regulatory changes which would obsolete new and expensive equipment designs. Also, modifications of the equipment must be approved by regulatory agencies which usually involves long periods of time for approval and consequently long delays in introducing the equipment to the marketplace. In summary, factory integrated lighting system design has not received widespread priority among equipment manufacturers, but considerable success has been achieved in stimulating manufacturers to supply some form of approved lighting system on their machines from the factory.

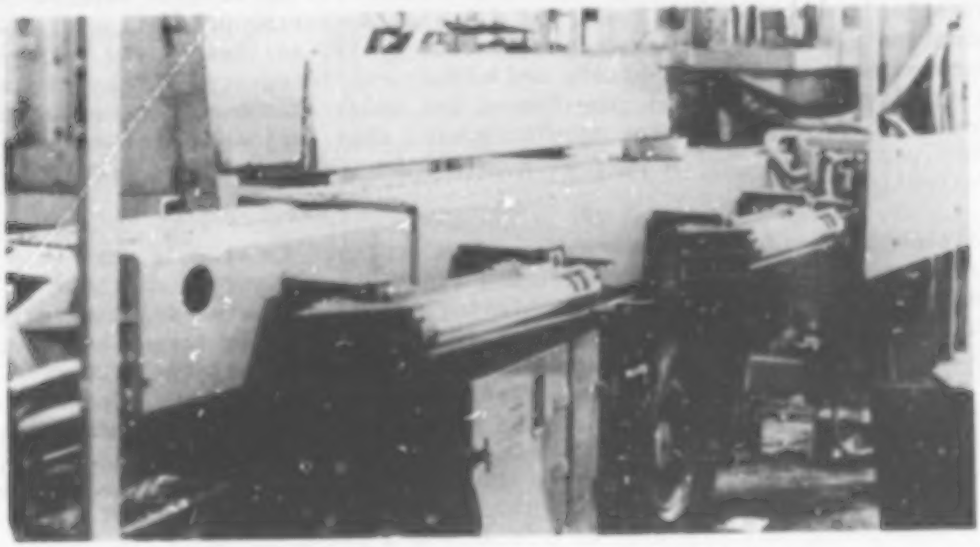

FIGURE 10. - "Factory Integrated" lighting system on a Fletcher DDM-13 diesel powered roof bolter.

FEASIBILITY STUDIES OF THE PROPOSED SURFACE COAL MINE ILLUMINATION STANDARDS

Surface mines in the past were primarily small operations and usually carried on during daylight hours, with little or no need for artificial lighting. But as stripping operations grew in size, more and more companies shifted to around-the-clock operations. With the advent of larger and more costly equipment being operated during non daylight hours, artificial lighting became a necessity. Initially, most lighting installed on stripping equipment was primarily for task purposes, with very little emphasis placed on safety lighting. As the frequency of accidents increased, the need for additional efforts in accident prevention became apparent. In the meantime, the Mine Safety and Health Administration (MSHA) began work on developing minimum lighting standards for surface coal mines and surface work areas of underground coal mines, and consequently published proposed mandatory standards.

Safety Lighting for Draglines and Power Shovels

In cooperation with MSHA and the mining industry, the Bureau of Mines has undertaken a number of programs to demonstrate the feasibility of the proposed surface mine illumination standards. Recent studies have focused on the design, installation and evaluation of lighting systems for draglines and power shovels. One study has been completed and a second study is nearing completion. Safety lighting systems for five draglines and one power shovel have been designed and evaluated. The first study involving three medium size draglines (Marion 184M, 12-cu-yd, Page 7-32, 20-cu-yd, Marion 7800, 28-cu-yd) has been completed by Phoenix Products Co. under contract to the Bureau of Mines. A more detailed discussion of this project is reported on in a separate paper of these proceedings[5]. The second study was contracted to Mine Safety Appliances Co. and is nearing completion. This study is also reported on in a separate paper[6] and involves lighting systems for two large draglines (Bucyrus-Erie 1450, 60-cu-yd, Bucyrus-Erie, 176-cu-yd) and one power shovel (Marion 5900, 105-cu-yd). An outgrowth of the second study has been a re-evaluation of the proposed lighting standards relating to the walkways, ladders and gantries that exist on dragline main frames and booms. Currently, these areas are required by the proposed standards to be illuminated to 5.0 foot candles. As the lighting designs for these areas progressed, it became apparent that the amount of lighting required to meet the proposed standards would be extensive and costly, and consequently a follow-up study was undertaken to investigate the frequency and nature of use of these areas and walkways. The findings of the study showed that most of the walkways and work areas were used rather infrequently and only for maintenance and repair purposes. It was also found that when travel in these areas was necessary, it was usually performed during daylight and the machine was shut down. Some companies have argued that the lighting would have a detrimental effect on safety, because maintenance of the 50 to 100 luminaires and associated cabling needed to light these areas would increase the frequency of usage of the areas, and consequently increase the workers exposure to a hazardous environment. Others have argued that the extensive network of power wiring to the lights may expose the worker to increased electrical hazards, particularly when you consider the harsh environment that the wiring and fixtures would be exposed to (high vibration, shock, weather extremes). A report of these findings has been sent to MSHA officials for review. A possible solution to the problem would be to require that travel in these areas be performed only when the machine is shut down and during daylight hours, and if maintenance or repairs are necessary during nighttime, the worker should be required to carry portable lighting.

Operator response to the new lighting systems has been excellent with some reporting increased gains in productivity as well as safety. These reports suggest that presently supplied task lighting may be inadequate and that the additional safety lighting is providing increased visibility for production tasks.

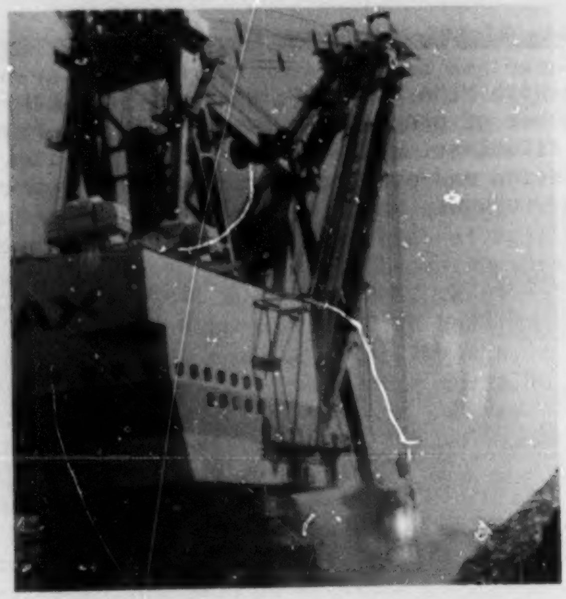

FIGURE 11. - Marion 5900, 105 cubic yard power shovel.

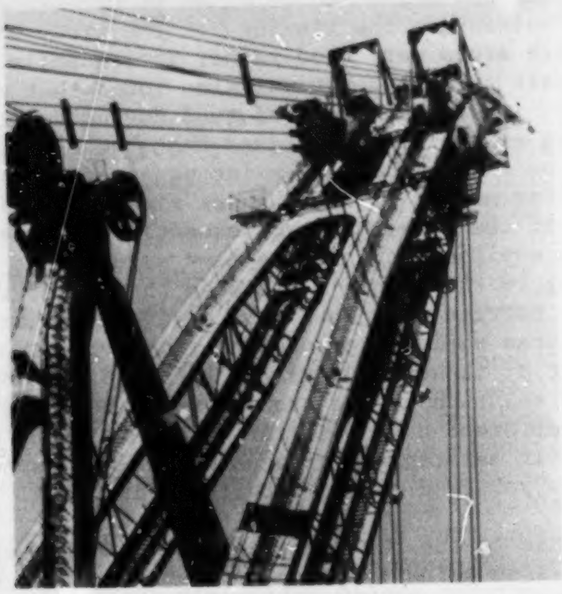

FIGURE 12. - Extensive network of walkways on board large draglines and power shovels.

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ILLUMINATION STANDARDS DEVELOPMENT FOR UNDERGROUND METAL AND NONMETAL MINES

Until recently, the major emphasis of the Bureau's illumination research program has focused on developing illumination standards and technology for underground coal mines and surface mining operations. In the future, as research problems are resolved in these areas; increased emphasis will be placed on the lighting needs of the underground non coal mining industry.

The underground non coal mining industry presents a unique mixture of diverse mining methods and environments which will require firm definition before illumination standards can be effectively developed. To this end, a first of a series of fundamental studies has recently been completed. Efforts of this program were directed towards quantifying and defining the large variety of mining operations, work tasks and work areas associated with underground non coal mines. Major work locations, activities, and equipment used in these locations have been described in detail. In addition, accident records have been analyzed and categorized according to work areas and tasks.

Follow-up studies are now underway to determine the minimum luminance requirements for these work areas and tasks. Present work involves the construction of a simulated mine laboratory where the various tasks can be analyzed in a controlled manner. The study will focus on answering basic questions, such as, what does the worker have to see to perform his task safely and how much light is needed to see? Work is also underway in developing a method for collecting in-mine reflectivity data. Since a large amount of reflectivity data is required to adequately describe the wide variety of work environments, a simple and expedious method for collection is essential. Research to date, has developed such a method. Briefly the method will use a photographic technique to capture the reflectivity data on film and will involve taking a picture of a scene or area of interest using standard black and white film and a camera equipped with a flash unit. Prior to taking the picture, a standardized gray scale card (Fig. 13) is placed in the scene. The picture is then taken and the exposed negative is developed and analyzed with an optical densiometer. By analyses of the optical density of the negative, reflectance values can be determined by comparing the optical density of the gray scale portions of the film with the optical density of other areas of interest in the scene. This procedure offers a number of advantages over other techniques using standard instrumentation, in that, relatively unskilled persons can be used in collecting the data and a permanent visual record of the test and environment is provided for future reference.

The intended outcome of this work will hopefully provide a set of guidelines or lighting standards that the underground non coal mining industry can utilize to improve the safety and productivity of their work environment. A more detailed discussion of this Bureau work is presented in a separate paper of these proceedings[2].

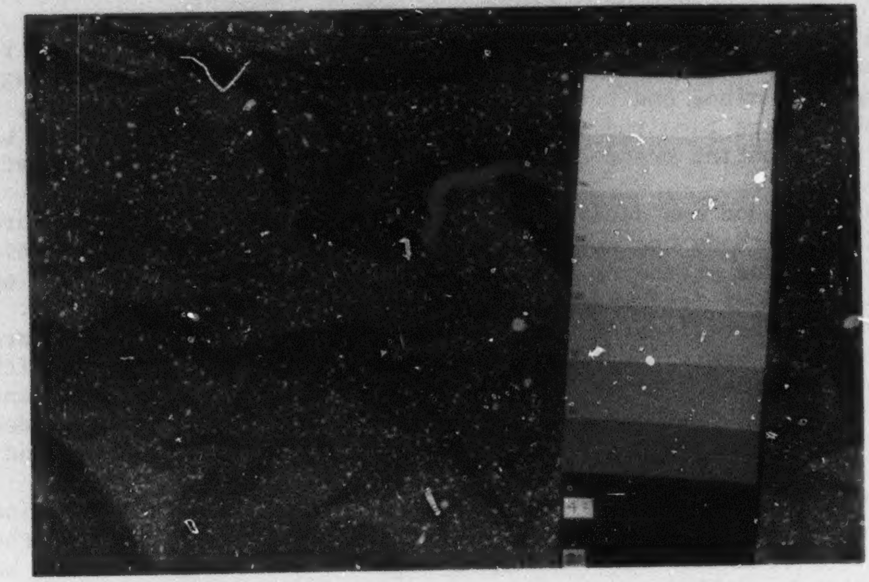

FIGURE 13. - Gray scale card used in photographic technique for determining reflectivity of mine surfaces.

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*Note: All references are contained in these proceedings.

TITLE OF PAPER: Underground Lighting
Acceptance Procedures

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UNDERGROUND LIGHTING SYSTEM ACCEPTANCE PROCEDURES

by

Freddy M. Huffman[1]

ABSTRACT

Federal regulations on underground coal mine lighting were issued in October 1976 and became effective in July 1978. These regulations established minimum illumination requirements and outlined procedures by which a Mine Safety and Health Administration (MSHA) acceptance for such a lighting system can be obtained and the criteria MSHA uses when issuing Statements of Test and Evaluation (STE's).

Methods and guidelines were adopted by MSHA's Beckley Electrical Testing Laboratory (BETL) to implement the requirements for issuing STE's for underground coal mine lighting systems. STE's are issued for underground coal mine lighting systems, machine lighting, shortwall and longwall lighting, and stationary lighting.

Acceptance of a lighting system depends on three major areas of consideration. First, it must be verified that the components of the system have been approved as permissible (will not ignite methane) and are suited for their intended use. Second, it must be determined that the system provides sufficient illumination for compliance with the lighting regulations. Third, the system must not create objectionable glare for the miners.

INTRODUCTION

Prior to 1969, equipment which traveled in excess of 4.0 km/hr (2.5 mph) was the only equipment in United States coal mines required to have luminaires installed. The only other required illumination found in U.S. coal mines was the coal miner's electric cap lamp. In 1969, Congress authorized the establishment of minimum illumination standards for underground coal mines, basing the decision upon the following facts:

1. The accident rate in U.S. coal mines was high due, in part, to the use of fast-moving, high-production equipment which operated in areas with restricted clearance.

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2. Research studies have shown that improved lighting in other U.S. industries has substantially decreased the accident rate.

In 1969, illumination expertise and approved permissible area lighting hardware were in very limited supply in the U.S. coal industry. Six years of experimentation, research studies, and numerous U.S. Bureau of Mines research contracts produced some lighting expertise and a few fixtures still used in U.S. coal mines today.

During initial installation of the new lighting systems on equipment in 1976 and 1977, problems were encountered due to glare. The lighting sources were found to be too bright for the confined work areas. To effectively minimize the discomfort glare experienced by coal miners, MSHA required the use of diffusers or louvers in conjunction with the lighting fixtures.

A procedure was needed whereby coal mine operators could purchase complete lighting systems and be assured that these systems met all the criteria of the Federal lighting regulations. Accordingly, MSHA developed and implemented the STE program for evaluation of a proposed underground coal mine lighting system to ensure that they meet all the requirements of the Code of Federal Regulations. The lighting system is evaluated for glare and the permissibility of the lighting component arrangement placed on the coal mine equipment. Evaluation for permissibility is an integral part of the program because all electric-powered coal-extraction equipment used in the working places of U.S. coal mines is required to be permissible. That is, any components that are added to the equipment must maintain the permissibility.

Lighting arrangements that meet the criteria for an MSHA-accepted lighting system are issued an acceptance letter called a Statement of Test and Evaluation (STE). For each STE-approved lighting system, a metal tag containing identification information is affixed to the machine.

The amount of illumination required for an STE was determined by U.S. Bureau of Mines research contracts on the minimal illumination necessary to safely perform underground mining tasks. Recommendations from these research contracts were for the coal surfaces to be illuminated to approximately 0.20 Nit (0.06 fL) surface brightness. Such surface brightness would enhance the miner's vision from the tunnel effect (cap lamp only) to total peripheral vision, enabling the miner to detect movement much more easily. Yet the 0.20 Nit (0.06 fL) level of surface brightness is low enough that a miner can easily adapt to an even lower light level, as when traveling from an illuminated face area to a coal mine area which is not required to be illuminated apart from the miner's cap lamp.

Due to the more complex instrumentation needed and the difficulty of taking sufficiently accurate reflected light measurements, incident light measurements are used for the issuance of STE's. Using an average coal mine reflectance of 4 percent, the surfaces required to be illuminated by the lighting standards must have an average of 21.5 Lux (2 fc) of incident light on any 0.37-m^2 (4-sq-ft) area to receive an STE. Applications for STE acceptance are submitted to BETL by lighting manufacturers, mining equipment manufacturers, and coal mine operators.

An STE application must contain the following:

1. Machine Layout Drawing - This drawing contains the mining machine dimensions, the lighting fixture locations, the mounting angle of each fixture, and the type of diffusion or shielding applied to each lighting fixture.

2. One-line Diagram Drawing - This drawing shows all the permissible components of the complete lighting system connected by one line as they would be installed on a mining machine.

3. Electrical Schematic Drawing - This drawing shows the purchaser of the lighting system how to electrically connect all the lighting fixture hardware.

4. Data - Data of all the required surfaces to be illuminated by the lighting regulations can be taken from actual machines or machine mock-ups. The data can be obtained from any one of these three sources:

   (1) Field data taken by a representative of BETL;

   (2) Laboratory data taken in BETL's mine simulator located at Beckley, West Virginia;

   (3) Laboratory data taken at an applicant's approved laboratory.

5. Electrical Drawing (longwall and shortwall applications only) - This drawing is used to ascertain that the lighting system meets all the electrical requirements for area lighting, i.e., maximum of 70 VAC to ground, overload and ground fault protection, and resistance grounding.

6. Short-circuit Calculations (longwall and shortwall applications only) - The calculations are used to ascertain that the lighting fixture circuit is protected by a suitable overcurrent device against minimal short-circuit currents.

MACHINE-MOUNTED LIGHTING SYSTEMS

Present STE requirements for machine-mounted lighting systems are as follows:

1. Continuous Mining Machines and Coal-loading Machines (Figure 1)

   In working places 1.1 m (42 in.) and above in which continuous mining machines and coal-loading equipment are operated, the areas which are required to be illuminated are as follows:

   (1) The coal face;

   (2) The ribs, roof, floor, and exposed surfaces of mining equipment which are between the face and the inby end of the shuttle car or other conveying equipment while in position to receive material.

To provide more direct light upon the coal face and allow the most efficient use of the available light, light measurements are not to be taken of the floor area between the cutter boom hinge pin or gathering head hinge pin and the coal face.

> In working places below 1.1 m (42 in.) in which continuous mining machines and coal-loading equipment are operated, light measurements are made within an area the perimeter of which is 1.5 m (5 ft) from any part of the continuous mining machine when measured parallel to the mine floor.

Operators of remote-controlled continuous mining machines experienced glare from the machine-mounted lighting fixtures located closest to the operator's locations. Since the operator of such machines is not confined to a location on the machine, the placement of any present-day lighting fixtures which would light up the coal roof, rib, and floor surfaces to the 21.5-Lux (2 fc) value became a source of discomfort due to glare. For this reason, STE acceptances of remote-controlled continuous mining machines operating in mining heights of less than 1.1 m (42 in.) are issued without taking light measurements on the right side outby the center of the main frame of the mining machine (Figure 2).

Present technology will not permit installation of light fixtures on rope-propelled, auger-type continuous mining machines in which miners are required to go inby the machines to set jacks or timbers without creating discomfort due to glare for the jacksetters or timbermen. Therefore, pending the development of glare-free illumination systems for these machines, illumination is not currently required in working places in which rope-propelled, auger-type continuous mining machines are operated if jacksetters or timbermen are required to work inby the machine operator.

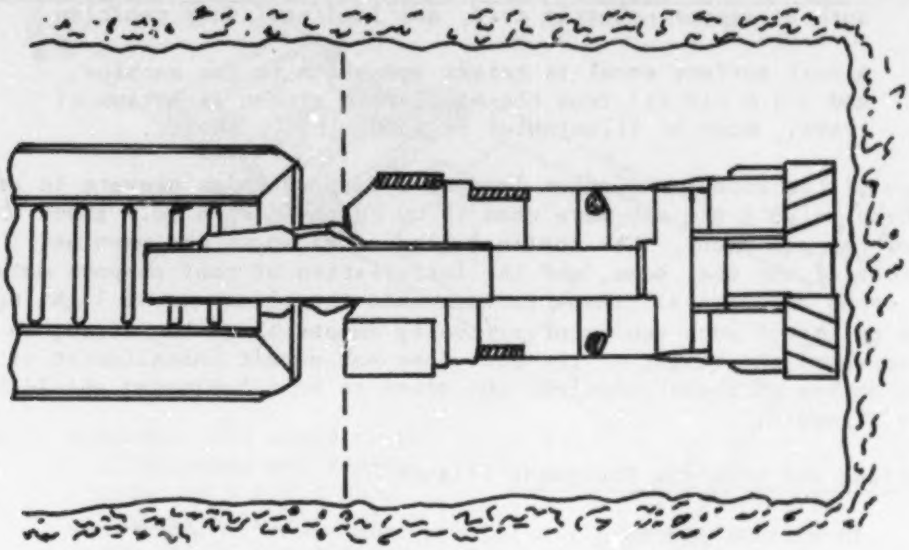


FIGURE 1. - Loader or continuous miner. The area to be illuminated is from the face to the outby end of the bumper.

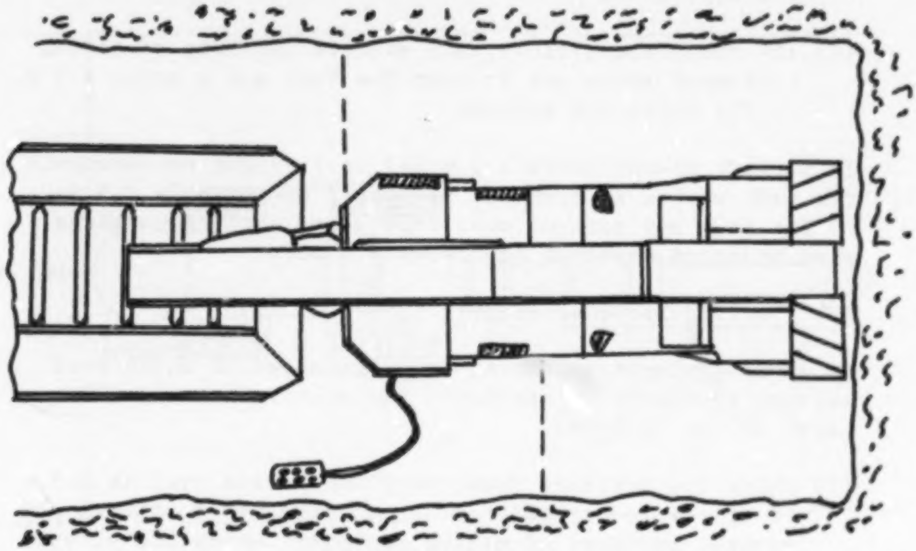


FIGURE 2. - Remote-controlled continuous mining machine. The area to be illuminated is from the bumper to the face on the left side of the machine and from the center of the main frame to the face on the right side of the machine when operated in seam heights less than 1.1 m (42 in.).

2. Self-loading Haulage Equipment and Other Self-propelled Vehicles, such as scoops, shuttle cars, and load/haul/dump vehicles

A coal surface equal in height and width to the machine, and 3.0 m (10 ft) from the machine in either direction of travel, must be illuminated to 0.20 Nits (0.06 fL).

Many of the scoops and other laod/haul/dump vehicles operate in coal seams where heights are not more than 15 to 20 cm (6 to 8 in.) above the height of the equipment. The confined clearances above the machine, undulations of the coal seam, and the installation of roof support material, such as cross headers--all these factors made the placement of lighting fixtures on top of such equipment virtually impossible. Therefore, in instances where the height of the coal does not permit installation of light fixtures on top of these vehicles, the areas to be illuminated should be as shown in Figure 3.

3. Cutting and Drilling Equipment (Figure 4)

In working places 1.1 m (42 in.) and above in which cutting or drilling equipment is operated, the areas which are required to be illuminated are as follows:

(1) The coal face;

(2) The ribs, roof, floor, and exposed surfaces of mining equipment which are between the face and a point 1.5 m (5 ft) outby the machine.

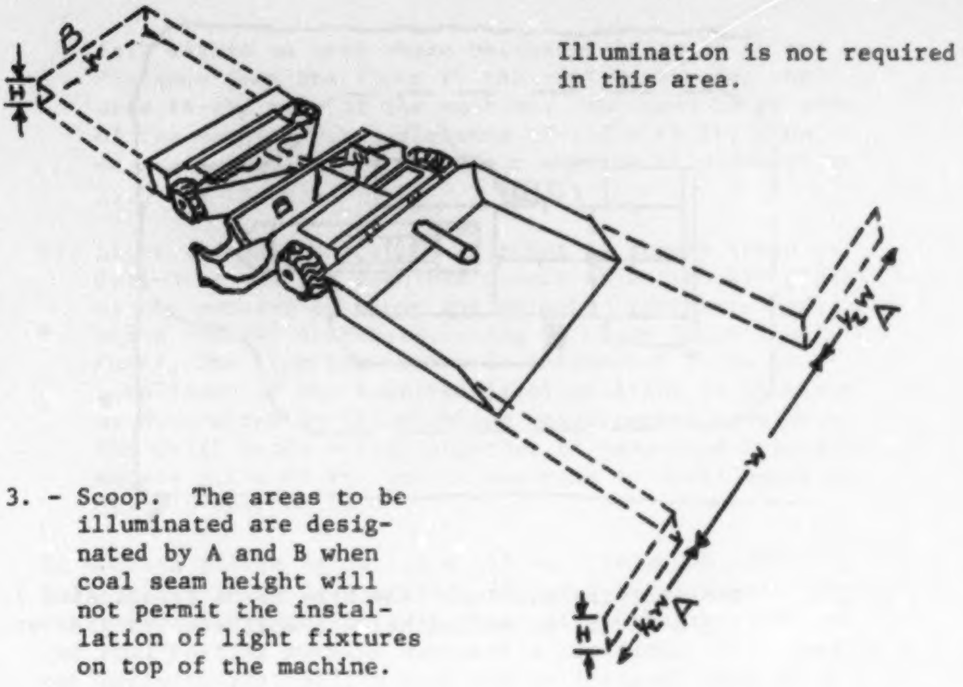
In working places below 1.1 m (42 in.), light measurements are made within an area the perimeter of which is 1.5 m (5 ft) from any part of coal drills and cutting machines when measured parallel to the mine floor.

4. Roof Bolting Machines (Figure 5)

In working places 1.1 m (42 in.) and above in which roof bolting equipment is operated, the areas which are illuminated are as follows:

(1) Where the distance from the floor to the roof is 1.5 m (5 ft) or less: the coal face, ribs, roof, floor, and exposed surfaces of mining equipment which are within an area the perimeter of which is a distance of 1.5 m (5 ft) from the machine when measured parallel to the floor.

(2) Where the distance from the floor to the roof is more than 1.5 m (5 ft): the coal face, ribs, roof, floor, and exposed surfaces of the bolting equipment which



Illumination is not required in this area.

FIGURE 3. - Scoop. The areas to be illuminated are designated by A and B when coal seam height will not permit the installation of light fixtures on top of the machine.

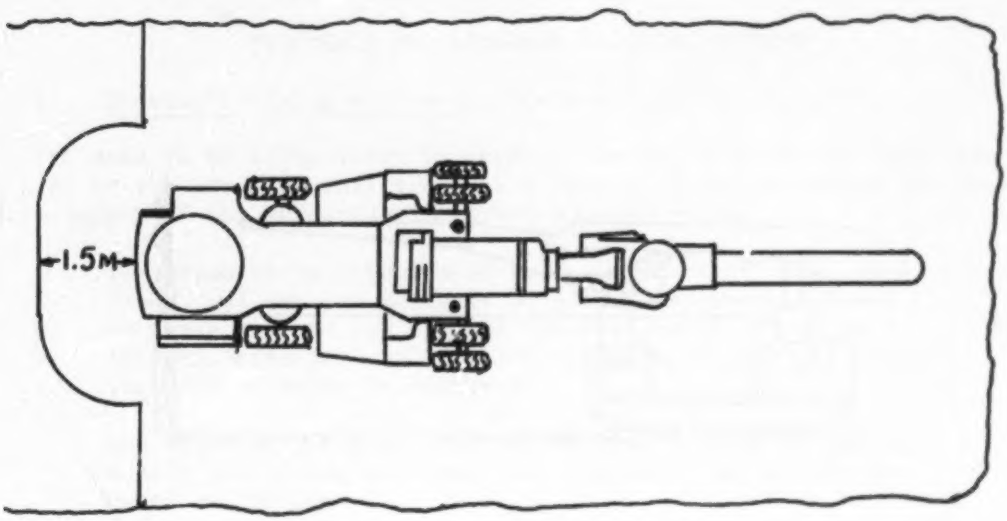


FIGURE 4. - Cutting machine. The area to be illuminated is from the face to 1.5 m (5 ft) outby the machine.

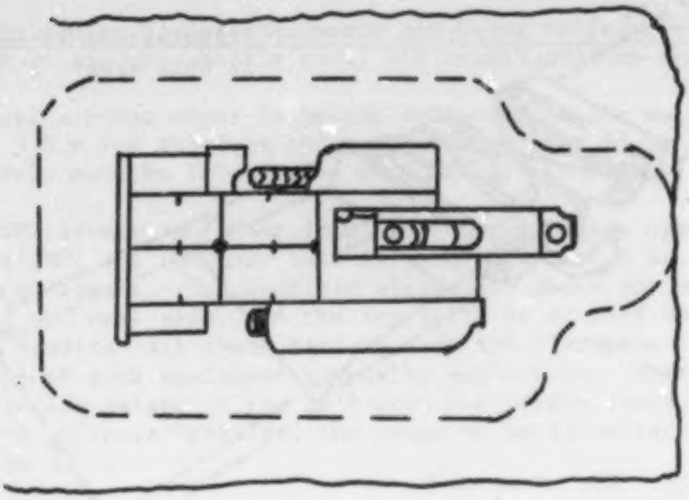


FIGURE 5. - Roof bolting machine. The area to be illuminated is 1.5 m (5 ft) or mining height, whichever is greater.

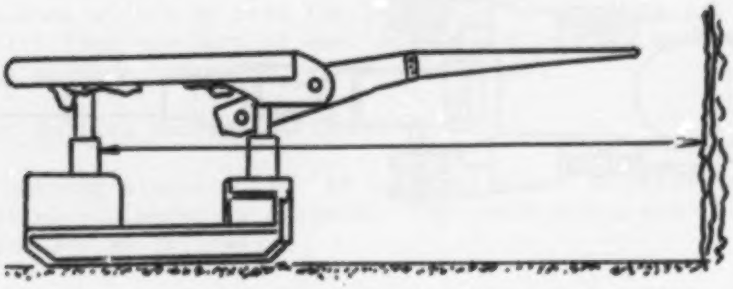


FIGURE 6. - Shortwall system. The area to be illuminated is from the face to the gob side of the travelway.

fall within an area whose perimeter is equal to the distance from the floor to the roof except for the area to the rear of the machine. The area to be rear of the machine for a distance of 1.5 m (5 ft) when measured parallel to the floor must be illuminated to 21.5 Lux (2 fc).

(3) Light fixtures installed adjacent to supply trays on dual-head bolting machines create objectionable glare to the machine operator and helper. Therefore, to allow removal or repositioning of these light fixtures, the lighting system is considered to be in compliance if the required level of light is provided as determined by illumination measurements made with the drill heads either together or separated approximately 2.4 m (8 ft) and in position to drill holes or install roof bolts.

In working places below 1.1 m (42 in.) in which roof bolting equipment is operated, lighting measurements are not taken within the area in front of and to the side of the roof bolting machine operator's position. This does not apply to roof drills that are an integral part of a continuous mining machine.

SHORTWALL AND LONGWALL LIGHTING SYSTEMS

1. Shortwall Mining Equipment (Figures 6 and 7)

The area to be illuminated is between the gob side of the travelway and the side of the block of coal from which coal is being extracted for the entire length of the self-advancing roof support system.

The areas to be illuminated would include the face, roof, floor, and exposed surfaces of mining equipment between the face and the gob side of the designated travelway. This illumination may be accomplished by stationary lighting only as shown in Figure 6.

The required areas of shortwall mining systems utilizing continuous mining machines (see Figure 7) may be illuminated as follows:

(1) For the section of the shortwall from which coal is to be extracted, the illuminated area is between the gob side of the travelway and the face.

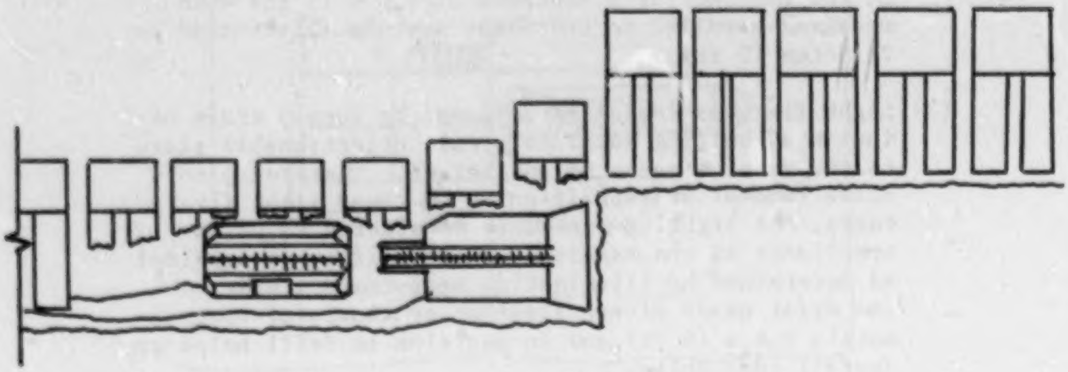


FIGURE 7. - Shortwall plan view. The area to be illuminated is from the gob side of the travelway to the face.

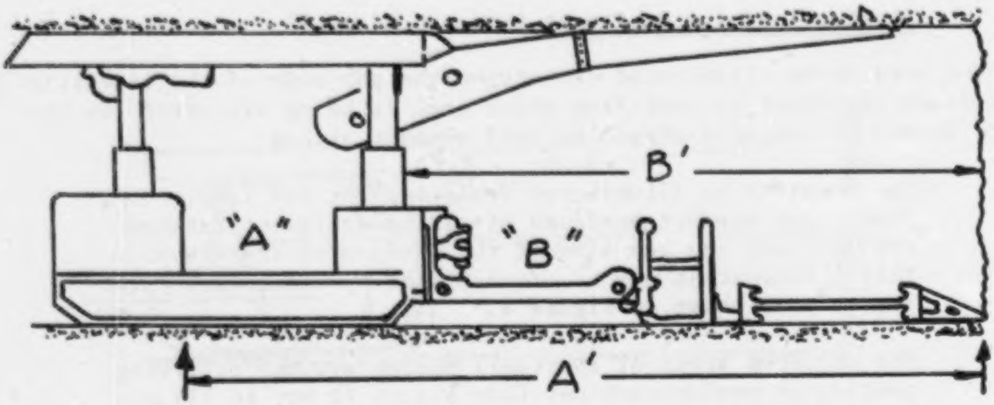


FIGURE 8. - Longwall system. The area to be illuminated is from the face to the gob side of the travelway. Designated Travelway "A", the area to be illuminated is A'. Designated Travelway "B", the area to be illuminated is B'.

(2) The continuous mining machine shall have machine-mounted lighting fixtures installed in accordance with an STE.

(3) For shuttle car haulage systems, the shuttle car must have an STE illumination system installed.

2. Longwall Mining Equipment (Figures 8, 9, and 10)

In seam heights 1.1 m (42 in.) and above, the following areas are required to be illuminated:

(1) The face;

(2) The area between the gob side of the travelway and the side of the block of coal from which coal is being extracted for the entire length of the self-advancing roof support system;

(3) The control station and the headpiece and tailpiece of the face conveyor;

(4) The roof and floor for a distance of 1.5 m (5 ft) horizontally from the control station, headpiece, and tailpiece.

In seam heights below 1.1 m (42 in.), problems have been encountered in illuminating the coal face and face conveyor to 0.20 Nits (0.06 fL) in longwall mining installations operating in coal seams under 1.1 m (42 in.) in thickness. The problems have been caused by the lack of sufficient clearance between the bottom of the roof support chocks and the side of the face conveyor, leaving little or no space through which light fixtures installed on the chocks can cast light on the face conveyor or the coal face. Therefore, in determining compliance with the illumination requirements for longwall mining installations operating in coal seams less than 1.1 m (42 in.) in thickness, measurements will not be taken on the face conveyor or the coal face. Measurements will be taken the entire length of the travelway. The following areas are required to be illuminated:

(1) The control station and the headpiece and tailpiece of the face conveyor;

(2) The roof and floor for a distance of 1.5 m (5 ft) horizontally from the control station, headpiece, and tailpiece.

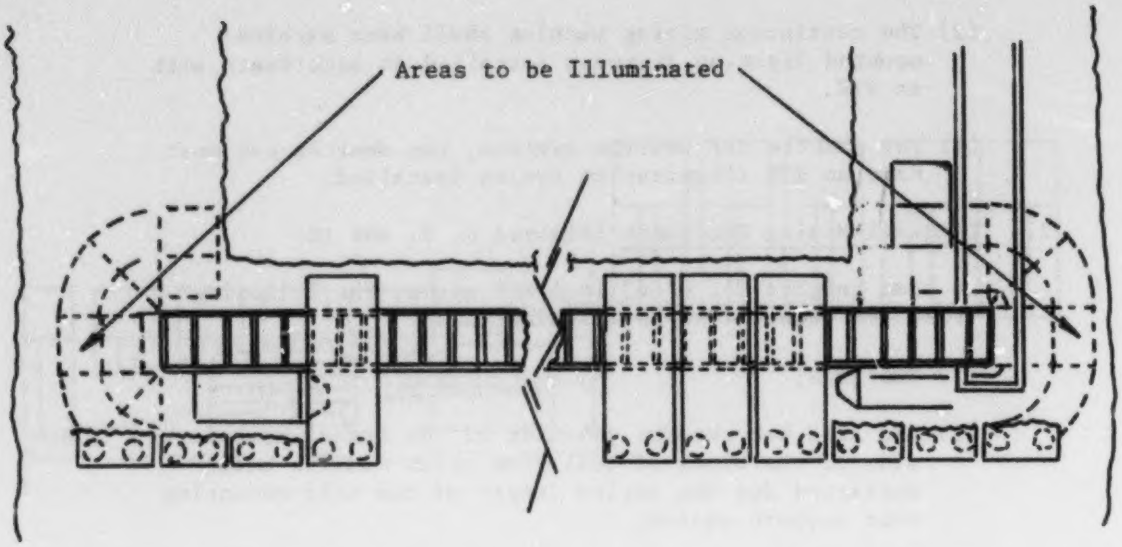

Areas to be Illuminated

FIGURE 9. - Headpiece and tailpiece. The area to be illuminated is 1.5 m (5 ft) around the headpiece and tailpiece.

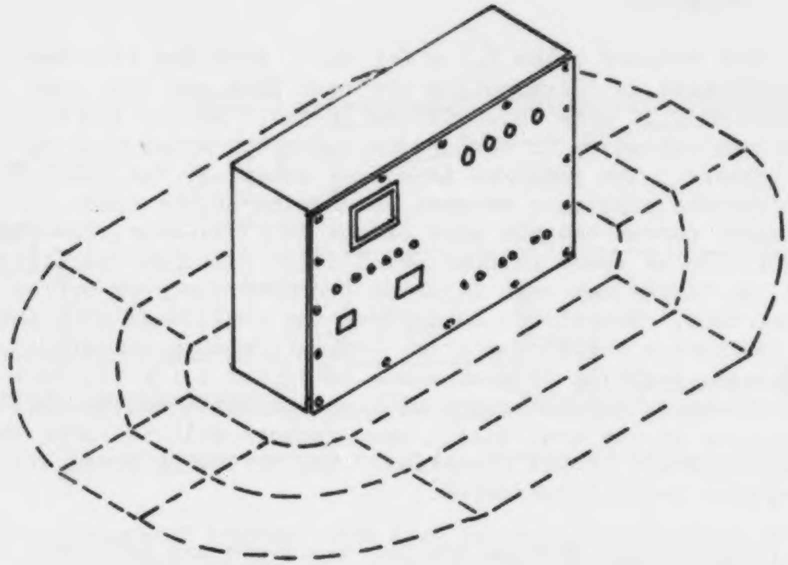


FIGURE 10. - Control station. The area to be illuminated is 1.5 m (5 ft) around the control station.

AREA LIGHTING SYSTEMS

The same areas are required to be illuminated by area lighting systems as by machine-mounted lighting systems. Although BETL has received several applications for area lighting, there have been no STE acceptances issued. Area lighting in U.S. coal mines has not been successful for three reasons:

1. The permissible power supplies are heavy and are especially difficult to maneuver in lower coal seams.
2. The constant hanging or routing of the electric cables to the lighting fixtures would diminish safety to the miners due to possible electric shock hazards.
3. The constant moving of the lighting fixtures and lighting fixture cables during the coal-extracting process would probably necessitate an additional worker per working section just for the movement of the lighting fixtures.

CONCLUSION

There are seven major U.S. manufacturers of lighting fixtures. Different lighting fixtures have different design advantages so that mine operators have a selection from which to choose the one that best suits their mining needs.

In some of the lighting fixtures which require ballastry, the ballast is an integral part of the approved fixture while other lighting fixture designs place the ballasts in a separate permissible enclosure.

Mine operators and maintenance personnel have had difficulty in maintaining systems containing ballast hardware. In addition, the mercury vapor and high-pressure sodium lamps experience lamp outages during appreciable dips in voltage. Such dips in voltage are common in U.S. coal mine working places and are the result of starting up large motors on board the coal-extraction equipment, such as the two ripper head motors on the continuous mining machines. These two ripper head motors are usually 126.75 to 152.1 horsepower (125 to 150 Hp) each. These lighting systems, designed with high intensity discharge (HID) lamps, generally tend to be brighter than lighting systems utilizing other lamp designs. Hence, MSHA receives more glare complaints about the HID systems and such systems have had less miner acceptance.

U.S. mine operators and maintenance personnel have also had difficulty in maintaining fluorescent lighting systems where the ballast is not an integral part of the lighting fixture.

STE-approved lighting systems designed with incandescent lighting fixtures have had an increasing acceptance in U.S. coal mines today for three main reasons--(1) lower initial cost; (2) ease of maintenance; and (3) ruggedness of the lighting fixture.

Mine operators are not required to obtain STE-approved systems and may elect to design and install systems of their own which meet all the criteria of the lighting regulations. BETL is available to help the mining industry with any lighting problems encountered in the effort to provide a safer and more productive environment for the Nation's coal miners.

TITLE OF PAPER: Illumination in South African
Gold Mines

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Mr. Hemp is a member of the TC-4.10 Mine Lighting Committee.

ILLUMINATION IN SOUTH AFRICAN GOLD MINES

by

Roger Hemp[1]

ABSTRACT

Some statistical information on men at work, production and productivity is used to explain both the interest in and the problems associated with illumination in South African gold mines. The present statutory requirements regarding mine lighting are stated, and some information is given on present illumination methods and conditions. The occurrence of inflammable gas in the gold mines is described, and while this is not a problem on some mines, there are mines where fairly large quantities of gas are encountered. This does not, however, have a very significant effect as far as most underground light sources are concerned.

Work which has been done on mine lighting in South Africa is described. This includes work by the Chamber of Mines, by one of the mining groups, and by the South African National Committee on Mine Illumination. This work includes investigations into visual acuity, colour blindness, and dark adaptation in black men, who form the great majority of the underground workers in South African mines; the development of an improved miners' cap lamp; some experimental work on stope illumination; and the progress which is being made in developing a set of recommendations for mine lighting.

INTRODUCTION

The South African mining industry employs a large number of workers. Statistics(1) for the calendar year 1979 indicate that a total of about 772,000 men are at work, of these about 453,000 work underground, while 319,000 work on surface. Of the 453,000 underground workers, about 333,000 work on gold mines, 51,000 on coal mines, and the remaining 69,000 on other mines. These figures show that just under 74 percent of the men working underground in mines in South Africa are working on gold mines.

The literature on mine illumination indicates that most work has been done on the illumination of coal mines and of other highly mechanised mines. While determined efforts are being made to change the situation, South African gold mines are at present not highly mechanised. Thus, while there is obviously much published work on mine illumination which is relevant to the illumination of gold mines, there are many situations underground in gold mines where equipment and techniques developed for mechanised mines are of little or no value.

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Some production figures will emphasize the lack of mechanisation on gold mines. During 1979, the gold mines milled some 86 million tons of gold-bearing rock. This amounts to just under 260 tons per annum per underground worker. South African coal mines, on the other hand, produced just under 104 million tons of coal during 1979. While the fact that some of this production as from opencast operations makes it difficult to calculate a corresponding figure per underground worker, it is estimated that coal production from underground mines is at least 1,600 tons per annum per underground worker, or at least six times the gold mine figure.

The low level of mechanisation in gold mines is primarily due to the nature of the ore deposit and the characteristics of the surrounding rock. The gold, sometimes accompanied by uranium, is contained in narrow conglomerate reefs, ranging in thickness from a few centimetres to several metres. The surrounding rock, and indeed the reef deposits themselves, are very hard, abrasive rocks, and thus not suitable for the mechanised mining methods used in, for example, coal mines. The generally narrow reef deposits also preclude the use of methods developed for the mining of massive ore deposits.

This situation has two important results as far as gold mine illumination is concerned. The first is the large number of men working underground, and the extent of this has been described above. The second is that there are a very large number of working places on any one mine, and as a result, there is an extensive network of shafts and haulages to serve the production areas, all of which ought to be properly illuminated. While this does present a problem of some magnitude, a far more serious problem is that of properly illuminating the working places themselves.

The mining methods used make this a formidable problem. Virtually all the rock broken underground in gold mines is broken by blasting. This requires the drilling of vast numbers of drillholes, and the need to suppress siliceous dust means that water is used in fairly large quantities, probably something like one ton of water per ton of rock broken. The frequent blasting operations prevent the installation of permanent or semi-permanent lighting in working places, and the wet and very rugged conditions mean that it is not practical to use mains-powered or cable-operated equipment.

Some idea of the extent of the underground workings in gold mines can be gauged from the following statistics(2). During 1979 there were, on average, some 3,400 working stopes on 39 gold mines; that is an average of just under 90 stopes per mine. The actual range was from 2 to 600 stopes per mine. During the same period there were, also on average, about 3,600 development ends, or also about 90 per mine. Production figures averaged just under 22,000 tons per annum per stope, and about 8,500 tons per annum per development end.

The above should help to explain the interest in illumination problems in gold mines, and hence the choice of subject matter for this paper.

The paper will describe the present statutory requirements for mine illumination and will give some indication of the methods presently used, and some results of surveys carried out to establish existing illumination levels. Brief descriptions will be given of research work which has been carried out by the Chamber of Mines of South Africa, and the work which is presently being done by the recently formed National Committee on Mine Illumination will be described.

STATUTORY REQUIREMENTS

Chapter 15 of the Regulations made under the Mines and Works Act [Act No. 27 of 1956] deals with lighting, safety lamps and contraband. Most of the regulations in this chapter deal with flame safety lamps, with portable lamps [this includes miner's cap lamps] and with permanent lighting fittings, all in the context of safety in mines where inflammable gas is encountered.

A few of the regulations do, however, deal in very general terms with illumination levels. These regulations are:-

15.1 "No person shall work or travel or cause or permit any other person to work or travel in any unilluminated part of a mine or works unless he or such other person carries a light.

15.2 "Adequate stationary lights shall be provided -

15.2.1 during working hours at all established stations, landing and loading places and other similar places in vertical and inclined shafts, winzes and planes where winding is being carried on;

15.2.2 at night at all places on surface where work is being carried on. For the purpose of this regulation and regulation 15.3.2 "night" shall mean that period of time from half-an-hour after sunset to half-an-hour before sunrise.

15.3.1 "All places where winding, driving, pumping or other machinery is erected, in the proximity of which persons are working or moving about, shall be so lighted that the external moving parts of such machinery whilst in operation are clearly visible.

15.3.2 "At all times underground and at night on surface the leading end of every moving train operated by a locomotive or any other power-driven vehicle, as well as every moving locomotive or other power-driven vehicle unattended to trucks or other

> conveyances, shall be provided with an effective bright light shining in the direction of travel."

While these four regulations are specific about the places which must be illuminated, the illumination levels which must be achieved are not defined in scientific terms at all, and depend upon such subjective phrases as "adequate," "clearly visible," and "effective bright light."

It must also be noted that the regulations do not require all places in a mine to be illuminated by sources other than the cap lamp. There are many working places in a gold mine which do not fall under the provisions of regulations 15.2, 15.3.1 and 15.3.2, and regulation 15.1 thus requires that in these places the miner's cap lamp must be used and may be the sole source of illumination.

PRESENT ILLUMINATION METHODS AND CONDITIONS

A short answer to the question of how gold mines are illuminated at present would be that they comply with the present Regulations, as described in the previous section. However, this statement does not give very much information, and an attempt will be made in this section to give some details, albeit still in general terms.

Before giving any details of installations, or information on illumination levels, the situation regarding the presence of inflammable gas will be described.

South African gold mines range from mines in which significant quantities of methane have never been found [and which are mines in which naked flames are allowed], to mines in which large quantities of methane are found; so large in at least one instance that a methane drainage system is installed, and the collected methane is used on surface for steam raising in a boiler installation.

While South African mining regulations made provision for a mine to be declared "fiery" there are, to the best of the writer's knowledge, no gold mines which have been declared as completely fiery mines, although any gold mine which does encounter methane will generally be required to comply with some of the regulations applying specifically to fiery mines.

These regulations will generally restrict equipment which may be installed at or near current working places to that which is either flameproof or intrinsically safe, but will not place restrictions on equipment installed in downcast shafts and main intake airways. Because hoisting, travelling, and the transportation of materials is almost without exception done in downcast shafts this means that the luminaires used for the permanent lighting installations mentioned in Regulations 15.2 and 15.3.1 need not generally be flameproof.

The illumination of such places as electrical sub-stations, pump stations, shaft stations, underground workshops, haulages and winch sites is generally achieved using either incandescent or fluorescent lamps, sometimes in luminaires, but often, particularly with incandescent lamps, just using the bare lamp. In some situations other lamps are used, such as tungsten halogen, mercury vapour, or other discharge lamps. One installation using high-pressure sodium lamps to illuminate an underground winding engine chamber has been described(3).

Most haulages which are illuminated use incandescent lamps. While the capital costs of these are low, the operating costs are high. As in most other countries, electrical power costs in South Africa are increasing steadily, and one very rough calculation indicated that, for equal illumination levels, a system using fluorescent lamps instead of incandescent lamps was justified on economic grounds. The fluorescent lamp system obviously had a much higher capital cost than the incandescent lamp system, but the savings in operating costs were sufficient to offset the capital cost difference within two years.

Some idea of the illumination levels existing underground in gold mines can be obtained from two different sources. The first is a paper by van Graan et al(4) which gave the results of surveys carried out by the staff of the then Human Sciences Laboratory of the Chamber of Mines of South Africa. The following table gives the average illuminance measured in various working places.

	Average Illuminance, lux	
	1971 work (ref 4)	1981 work (ref 5)
Electrical sub-stations........	82	67
Conveyor belts.................	64	66
Pump stations..................	56	67
Shaft stations.................	48	71
Workshops......................	44	70
First aid stations.............	40	47
Tips...........................	34	36
Winches........................	27	17
Waiting places.................	17	19
Haulages.......................	7,5	18

The table also gives the results of some more recent measurements. These measurements are reported by Schröder and van der Walt(5), and are averages of routine measurements made by staff of the environmental control departments on the mines.

While some differences are apparent in the average figures given in the above table, these differences are not very large and it can be concluded that there has been little change in illumination over the period between the two surveys.

It is important to appreciate that the tabulated figures are averages. Very considerable variations occur, both on a particular mine and between different mines. This is illustrated in Figure 1, which shows frequency distributions of observed illuminance values at winches for the two surveys.

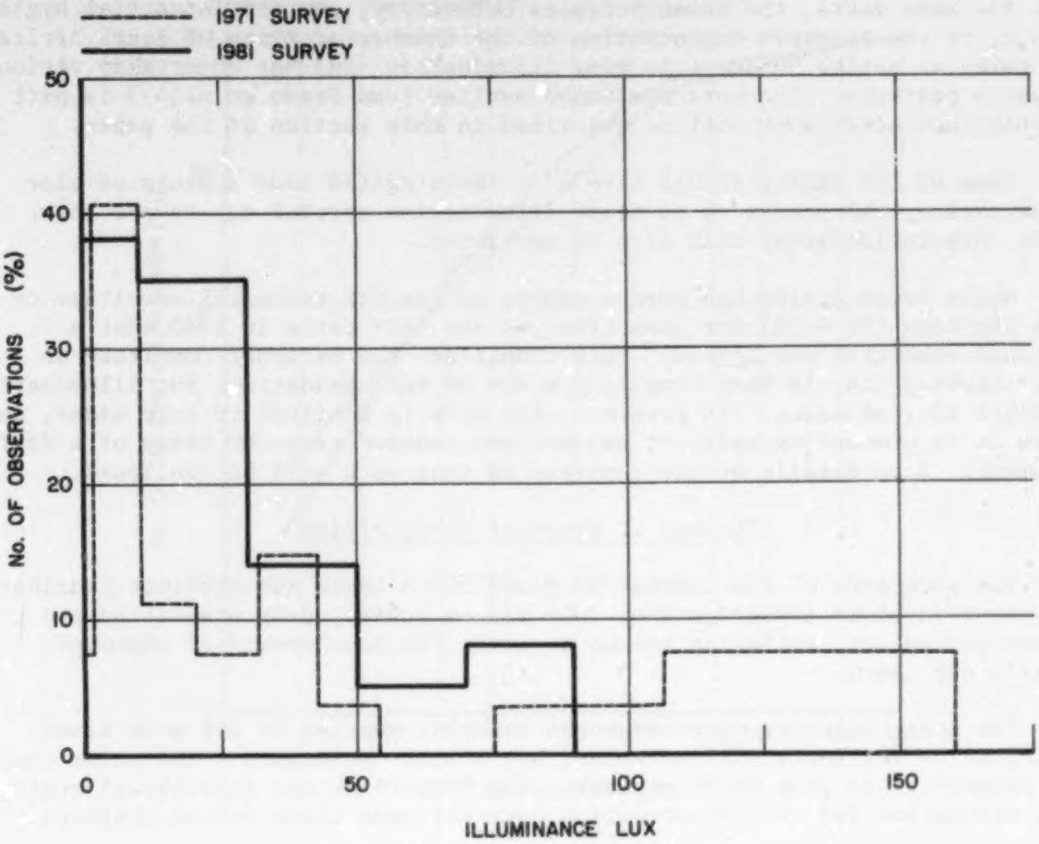

Figure 1.

Neither of the two surveys gave the results of illumination measurements in stopes or development ends. The reason for this is that, as mentioned earlier, the sole source of light in these places is the miner's cap lamp. Under these circumstances, it is an extremely difficult problem to obtain measurements that adequately represent the illumination conditions in the working place. van Graan et al(4) did quote a value of between 2 and 4 lux for stopes, but this figure was based upon a study of cap lamp performance and not upon measurements taken in the stope.

INVESTIGATIONS INTO MINE ILLUMINATION

Investigations into mine illumination in South Africa have been undertaken by three different bodies.

For many years, the Human Sciences Laboratory, now the Industrial Hygiene Branch, of the Research Organisation of the Chamber of Mines of South Africa has taken an active interest in mine illumination, and has undertaken various research projects. The work mentioned earlier [van Graan et al(4)] is part of this, and other work will be described in this section of the paper.

Some of the mining groups have also investigated some aspects of mine illumination, and some work on stope illumination carried out by the then Union Corporation group will also be mentioned.

While South Africa has been a member of the CIE technical committee on mine lighting [TC-4.10] for some time, it was only early in 1980 that a national committee was formed. This committee, the National Committee on Mine Illumination, is busy compiling a set of recommendations for illumination in South African mines. At present, this work is confined to gold mines, and while it is proceeding well, it has not yet reached even the stage of a draft document. Some details of the progress of this work will be mentioned.

Chamber of Mines of South Africa

The work done by the Chamber of Mines falls under two distinct headings. The first involves investigations into visual acuity, dark adaptation and colour perception, while the second involves the development of improved miner's cap lamps.

The great majority of underground workers, whether on the gold mines alone, or on all South African mines, are black. Reference 1 indicates that the proportion is just on 94 percent. The investigations into visual acuity, dark adaptation and colour perception have all used black men as subjects.

The work has been reported on by van Graan et al(6) and by van Graan(7). Tests on visual acuity under different illumination levels, and on colour blindness, were conducted on a total of 500 men, whereas 60 men were tested for dark adaptation.

The visual acuity tests involved reading a Snellen chart under various conditions of illumination, when the subjects were either light-adapted or dark-adapted. It was concluded that the subjects tested had, in general, superior vision. but that, as would be expected, visual acuity decreased as the light level decreased. One way in which these results were illustated was by plotting graphs showing how the percentage of men having 6/6 vision varied with illuminance. These results are shown in Figure 2.

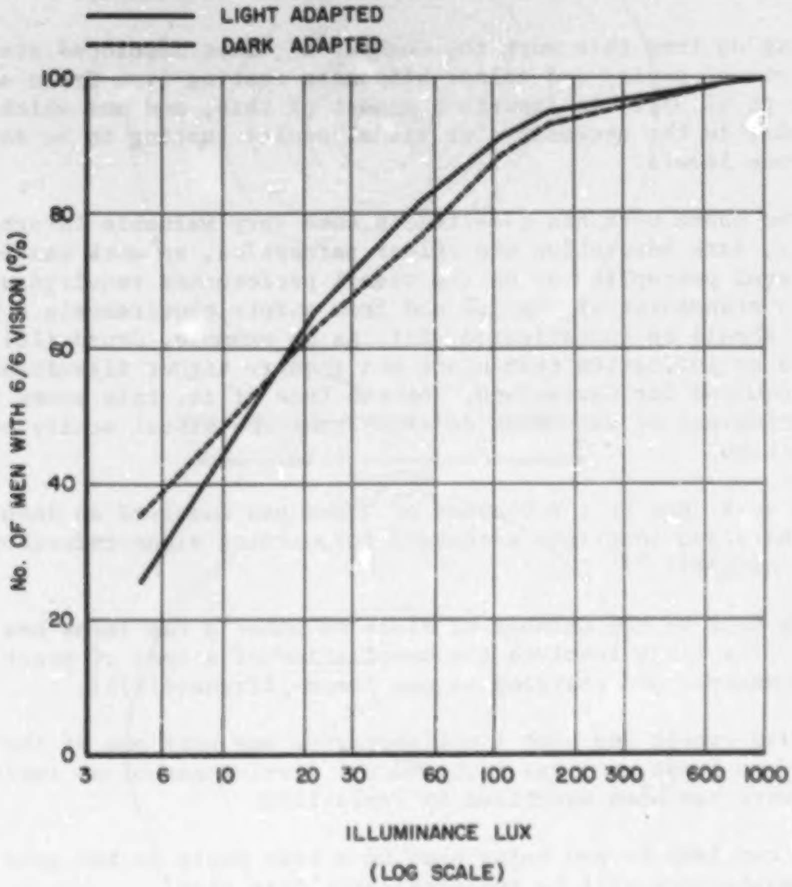

Figure 2.

Color blindness tests utilized the standard Ishihara colour blindness test chart and the results showed that only 7 out of the 500 men (1,4 percent) suffered from colour blindness. This figure is significantly lower than the figure of around 8 percent generally quoted for Caucasian males.

This low incidence of colour blindness amongst black males is generally supported by other work, quoted by van Graan et al(6), but one study revealed an incidence of 34 men out of 372 tested, or just over 9 percent.

Dark adaptation times varied from 11 minutes to 105 minutes, with an average of just under 33 minutes. These times appeared to be generally longer than those normally quoted. A maximum time of about 40 minutes is usually quoted for complete dark adaptation, whereas this study indicated that only 77 percent of the men tested were dark adapted within 40 minutes.

Following on from this work the Chamber of Mines developed standard methods for visual acuity and colour blindness testing [van Graan et al(8) and van Rensburg et al(9)]. An important aspect of this, and one which the authors stress, is the necessity for visual acuity testing to be done under low illuminance levels.

While the above work has resulted in some very valuable information on visual acuity, dark adaptation and colour perception, no work has been done either on visual perception or on the visual performance required underground, both from the standpoint of the job and from safety requirements. This is an aspect which should be investigated, for, as an example, Grundy(10) has stated that there is an indication that black men require higher illuminance values than those required for Caucasians. On the face of it, this seems to conflict with the conclusions of van Graan et al(6) that the visual acuity of their subjects was high.

Further work done by the Chamber of Mines has involved an investigation into the colours and contrasts necessary for warning signs underground [Davidoff et al(11)].

The work done by the Chamber of Mines on miner's cap lamps has covered two aspects. The first involves the compilation of a code of practice for the repair, maintenance, and charging of cap lamps [Blignaut(12)].

The second aspect has been a collaborative one with one of the local suppliers of cap lamps, and has involved the development of an improved cap lamp. This work has been described by Taylor(13).

The new cap lamp is now being used on a test basis on two gold mines, and full-scale manufacture will be achieved later this year.

The cap lamp uses a new headpiece fitted with a tungsten halogen bulb (4V, 1A). Lumen output is considerably greater than present lamps. A vital part of the new lamp is the greatly improved lead-acid battery. This is a completely sealed unit with a 16Ah rating, compared with the 10Ah rating of a conventional battery. The mass of the new battery is significantly lower, 1,96kg instead of 2,24kg.

Figure 3 shows some preliminary illumination figures, and compares the new lamp with the old.

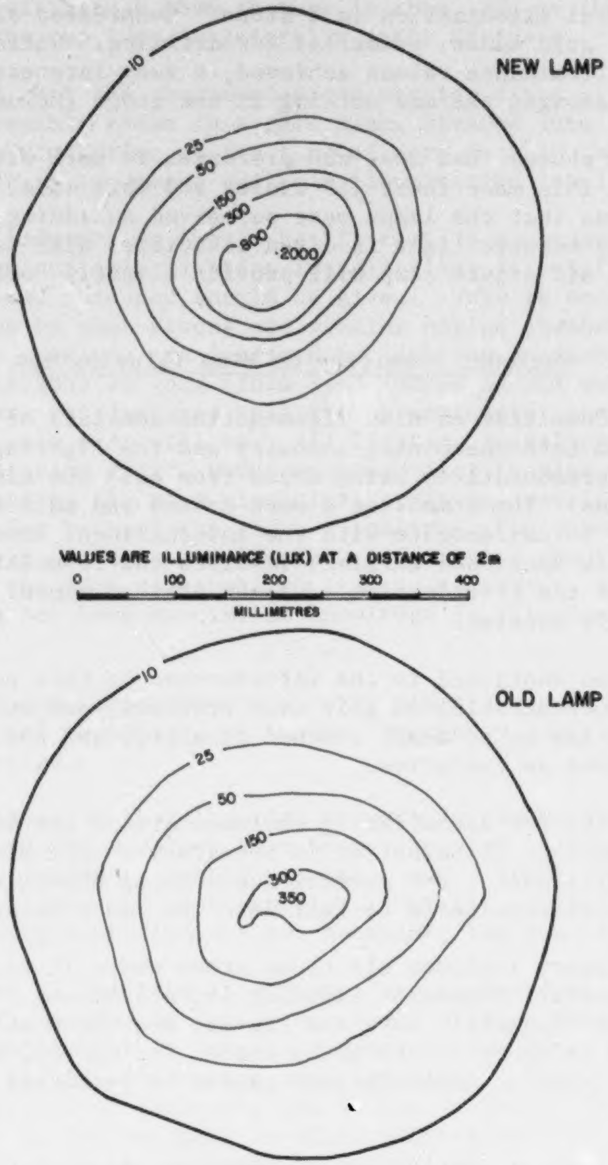

Figure 3.

Union Corporation

Earlier on the work done by the then Union Corporation group on stope, illumination was mentioned. In this work several compressed air-driven lamps were used for general illumination in a stope. Compressed air is used very extensively on all gold mines, primarily for drilling. While no figures are available of the illuminance values achieved, a very interesting attitude survey was conducted amongst the men working in the stope [Melamed et al(14)].

This attitude showed that most men preferred to work with extra illumination, feeling that this made their job easier and more safe. The main negative comment was that the lamps were perceived as adding to the heat in the stope, probably because light is often associated with warmth. In actual fact, a compressed air-driven lamp will provide slightly cooler conditions in the stope.

National Committee on Mine Illumination

The National Committee on Mine Illumination consists of sixteen members; they are drawn from both the mining industry and the lighting industry, the mining industry representatives being drawn from both the mining groups and the Chamber of Mines. The committee's work covers two main aspects. The first is naturally to collaborate with the international committee, TC-4.10, while the second, as mentioned earlier, involves the formulation of a set of recommendations for the illumination of South African mines. These two activities obviously overlap.

For the reasons mentioned in the introduction to this paper the committee is at this stage concentrating on gold mine problems, and while this work is proceeding well it has by no means reached finality, and the information given here must be regarded as tentative.

A starting point for establishing recommendations for mine illumination was the obvious one that illumination is necessary in all places where men are required to work or travel. For convenience working places and travelling ways in the mine were considered to fall into two basic categories.

The first category includes all those areas where it is both practical and advisable to install permanent lighting installations. This thus includes all areas where men frequently work and travel, and where no blasting takes place. The second category covers areas where, for safety, economic, or practical reasons lighting installations cannot be permanent. This category thus includes

a. all current working areas, where the regular blasting operations make it impossible to install permanent lighting installations.

b. areas such as airways in which no regular travelling takes place, vertical shafts, haulages, and crosscuts no longer in regular use, etc. The only time illumination is required in these areas is when men do have to travel through them to work in them, and at these times the cap lamp is generally quite adequate.

It was envisaged that the recommendations should, first of all, provide a list of all of the possible areas in a gold mine, divided into the categories described above. An examination of the type of work done in the various areas would make it possible to recommend suitable illumination levels for these.

While the above information should be all that is necessary for a lighting engineer to design suitable lighting installations it was felt very strongly that additional guidance should be given. This is because while some lighting installations in such places are winding engine chambers, electrical substations, and pump stations are designed by lighting engineers, there are many lighting installations on gold mines [and indeed on all other mines in South Africa] which are not designed by lighting engineers, and it is impractical to expect that they ever will be. All lighting installations are installed by mine engineering staff, sometimes according to mine standards, sometimes as determined by the mine electrical engineer, section engineer, or electrical foreman. For both of the above situations, the committee felt that the recommendations should contain sufficient information about lamps and luminaires to enable the mine to establish its own standards, and to assist the engineer who does not have specialist knowledge in illumination to design an installation.

Other aspects of the recommendations cover miner's cap lamps, lighting systems for vehicles and mechanical equipment, emergency lighting systems, and warning notices and signs.

The present position is that the list of working places has been drawn up, and tentative illuminance values have been allocated to these. Information on lamps and luminaires is nearly complete, and a draft set of requirements for miner's cap lamps has been compiled. Finally, a list of areas where emergency lighting installations are necessary has been drawn up.

The determination of required illuminance values was done as follows. In the first place it was decided to follow the South African Bureau of Standards code for interior lighting(15) in several respects. The first was in deciding to specify levels of illuminance rather than luminance. This is by far the most useful way for practical purposes, but it can obviously be criticised, and it is intended to do further work on this, particularly by establishing typical reflectivity values for underground situations.

Illuminance values for all of the places in the permanent lighting category were taken from the SABS code, and the code was also used to specify glare index values where necessary. In all of these areas it is intended that all of the illumination should be provided by permanent, mains operated installations, and that while all men would obviously continue to wear cap lamps, it would not be necessary for these to be used in these areas.

Illuminance values for those working places in which blasting takes place regularly were considered on a somewhat different basis, mainly because it was difficult to find equivalent working places in the SABS code. These working places are mainly stopes and development ends.

As mentioned earlier, at present the miner's cap lamp is almost without exception the only source of illumination in these areas. This was felt to be undesirable, particularly from the point of view of safety, for a man's peripheral vision is virtually nil under these conditions. Thus, while at this stage, there is no really suitable light source available, particularly for stopes, the committee felt that it was very important for general illumination, albeit at a somewhat low level, to be provided in both stopes and development ends.

The lack of a suitable source of general illumination for use in stopes and development ends is seen as a serious problem which should be given more attention. While no detailed specifications have been drawn up, it would seem that a diffuse source is essential so as to avoid glare in the generally narrow stopes. Stoping widths vary from 0,94m to 2,22m, with an average figure of 1,38m.

The work on lamps and luminaires has covered such aspects as types of light sources, supply voltage, lamp caps, control gear, colour, lamp position, vibration, lamp life and lumen depreciation, restrike time, and light output and luminous efficiency.

The requirements for miners' cap lamps cover aspects such as battery characteristics - mass, shape, comfort, mositure, shock, vibration, corrosion and abrasion resistance, and cable anchoring, similar factors for the headpiece, and performance characteristics - such as light output, beam geometry, burning time, reliability, and cycling life. Lamproom management is also covered.

These are the portions of the recommendations that have been completed, at least in skeleton form, to date. No detailed information is given here because no finality has yet been reached. An important aspect of the work is that the committee intends to test the practicability of the recommendations by examining a section of a mine, and determining what changes would be necessary in order to comply with the recommendations, and what these changes would cost, both in capital costs and in operating costs.

In conclusion, it should be noted that the work the committee has done shows that it is in complete agreement with views expressed ten years ago, both by van Graan et al in their paper listed as reference 4, and by Martinson in a contribution to that paper. These views were that the only way to bring about improvements in mine illumination is to establish a standard code of practice, and that improvements in mine illumination can only lead to safer underground conditions and more productive work from the men working underground.

ACKNOWLEDGEMENTS

The author has benefitted greatly from all of the discussions with his colleagues on the National Committee on Mine Illumination, and it is a pleasure to be able to express thanks to them all here.

Thanks are also due to Rand Mines Limited, both for their support in general, and for permission to publish this paper.

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TITLE OF PAPER: Mine Lighting Research and
Development Work in Bulgaria

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Eng. Ganchev is a member of the Bulgarian National Committee of Illumination, and since 1975 has been a member of the TC-4.10 Committee.

MINE LIGHTING RESEARCH AND DEVELOPMENT WORK IN BULGARIA

by

Gancho Ganchev[1]

ABSTRACT

Mine-lighting research in Bulgaria has had an intensive development program in the last 5 to 6 years, involving investigations of the following main problems:

1. Creating a method for measuring and inspection of mine lighting installations.
2. Determining the reflection characteristics of coal mines and metal mines in view of mine-lighting projection by luminance.
3. Creating standard levels of illumination of underground and open-pit mines.
4. Creating luminaires for underground metal mines.
5. Developing methods for mine-lighting design.

The paper discusses the research done in Bulgaria on each of these problems, giving some of the basic considerations underlying the research and some results of the work done.

TEXT

Electric lighting in an underground mine in Bulgaria was for the first time applied in 1895, in the Pernik coal mine. Till the 9th September 1944 mining in our country was underdeveloped.

Today Bulgaria produces 30 million tons of coal--77 percent of them from open pit mines.

Mine developing gave rise to the electrification of mines as well as to mine lighting.

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Mine lighting research has marked an intensive development in the last 5 to 6 years. The main problems worked out in the investigation are:

1. Creating a method for measuring and inspection of mine lighting installations.

2. Determining the reflection characteristics of coal mines and metal mines in view of mine lighting projection by luminance.

3. Creating standard levels of illumination of underground and open-pit mines.

4. Creating luminaires for underground metal mines.

5. Developing mine lighting design methods.

The first problem; i.e. creating a method for measuring and estimating of mine lighting, arose from the necessity of controlling and inspecting mine lighting.

It is necessary to define the least number of measurements and the appropriate places to be measured in the mines with respect to deciding whether mine lighting is adequate to standards or not. To answer the above question, many illuminance measurements in different points and in various mines have been made.

Figure 1 shows a diagram of the measuring. The illuminance was measured in the cross-point of a net with a step of one metre.

When the mine working is long and narrow, the illuminance is measured along the axis of the floor and at every metre.

On Figures 2 and 3, results obtained from measurements in a gallery in different metal mines are shown.

After statistical data processing, the curves of frequency distribution are obtained.

On Figures 4 and 5 are shown the curves of distribution for different working places; e.g. in chamber mining (a transformer substation, a water pumping chamber, a medical station, a locomotive depot, a workshop, etc.). The results are subordinated to normal distribution. The curves of illuminance distribution for a gallery are shown in Figure 6. They have binominal distribution.

It is expedient to estimate the illumination according to the mean level of illuminance E_m and to the dispersion in case the results correlate with Gaussian distribution.

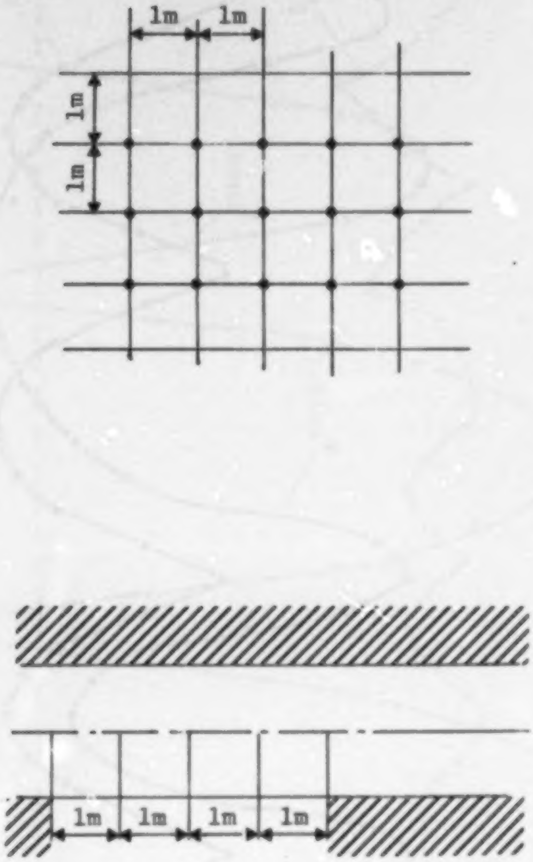
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Figure 1

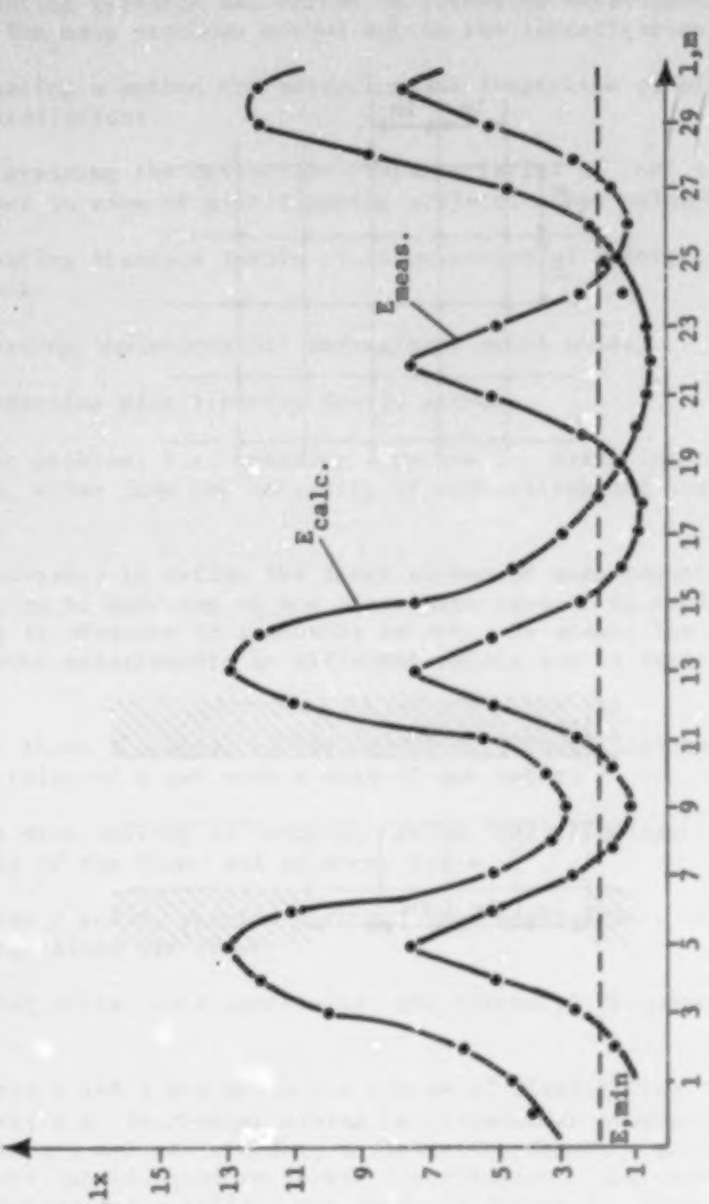
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Figure 2

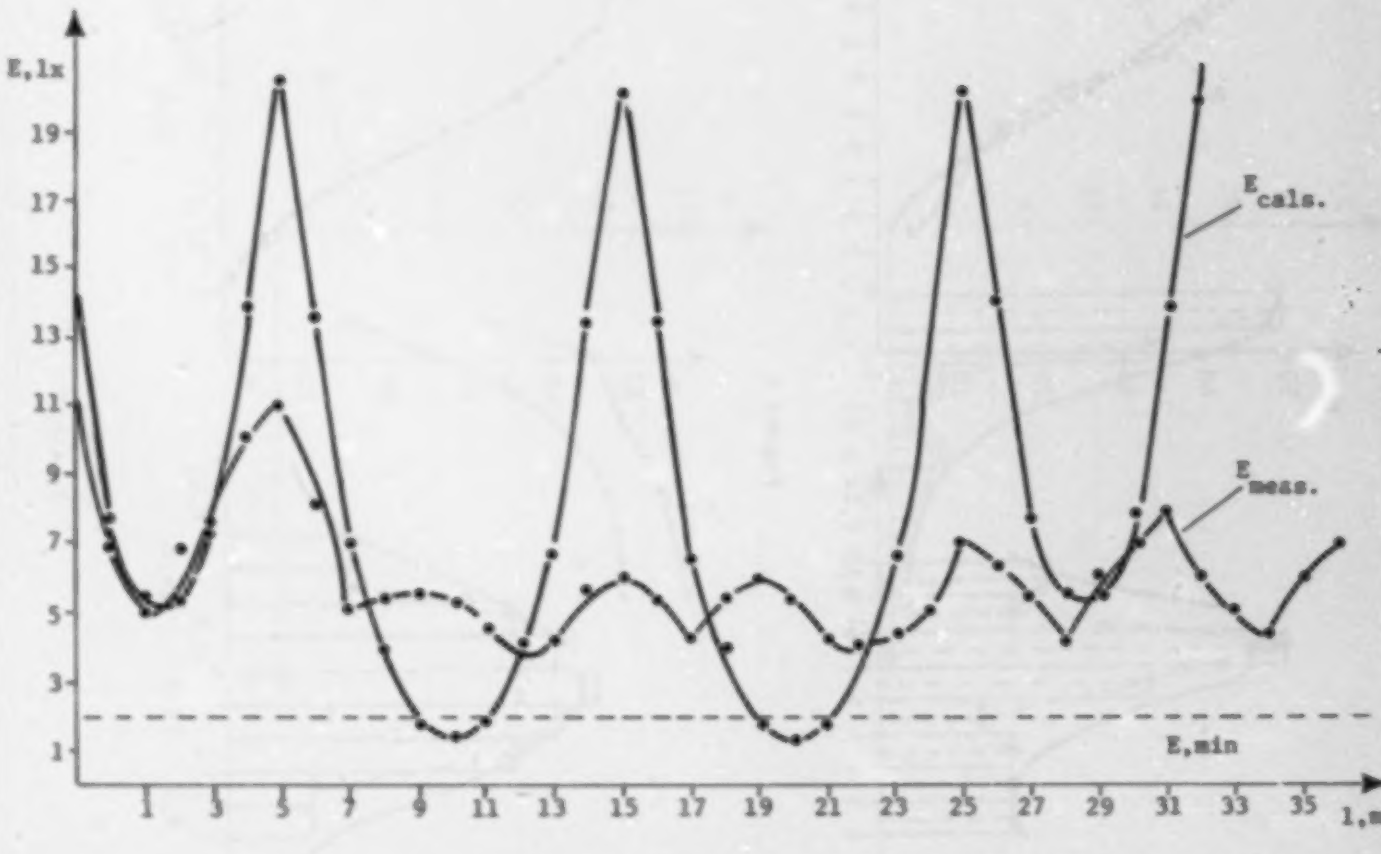
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Figure 3

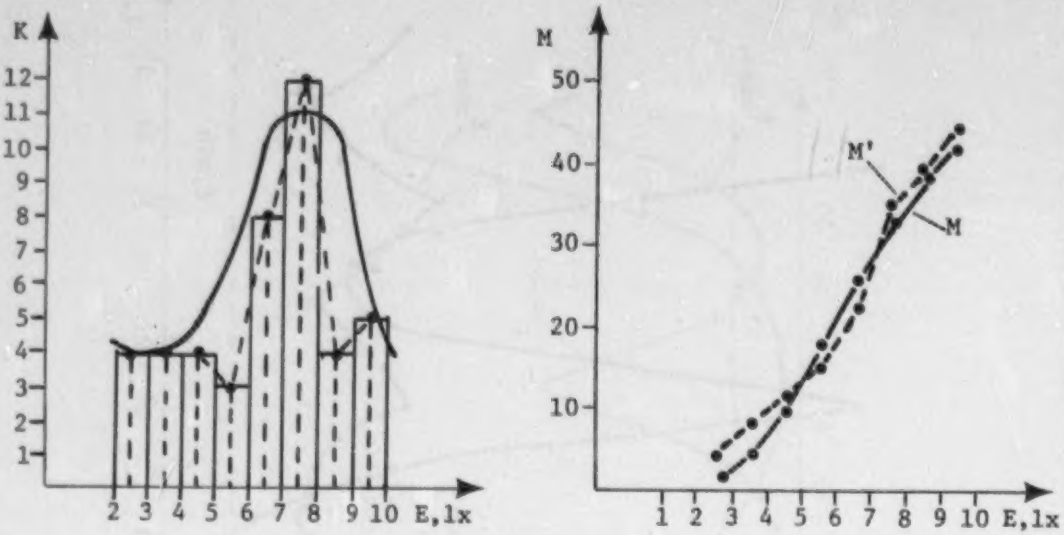


Figure 4

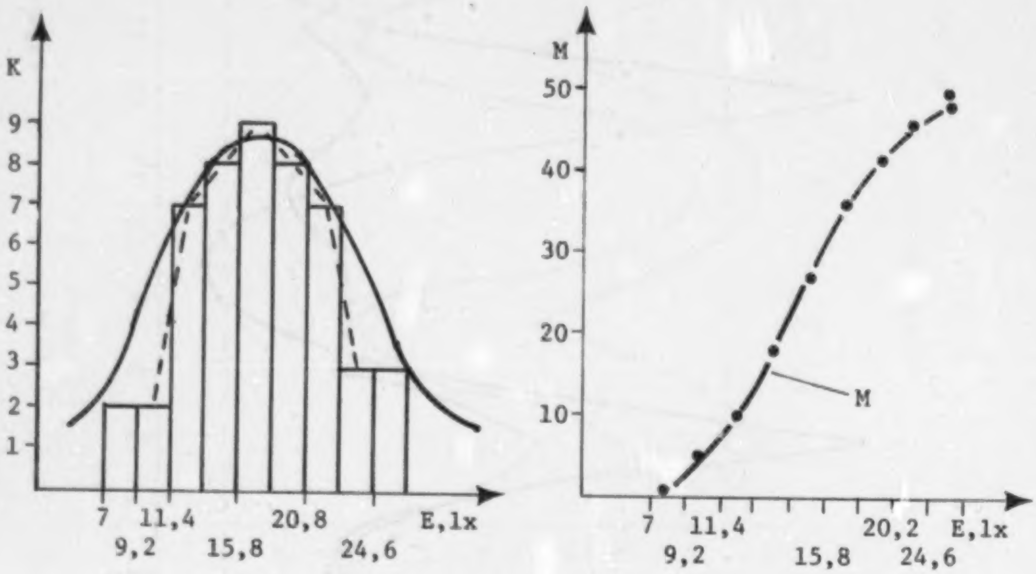
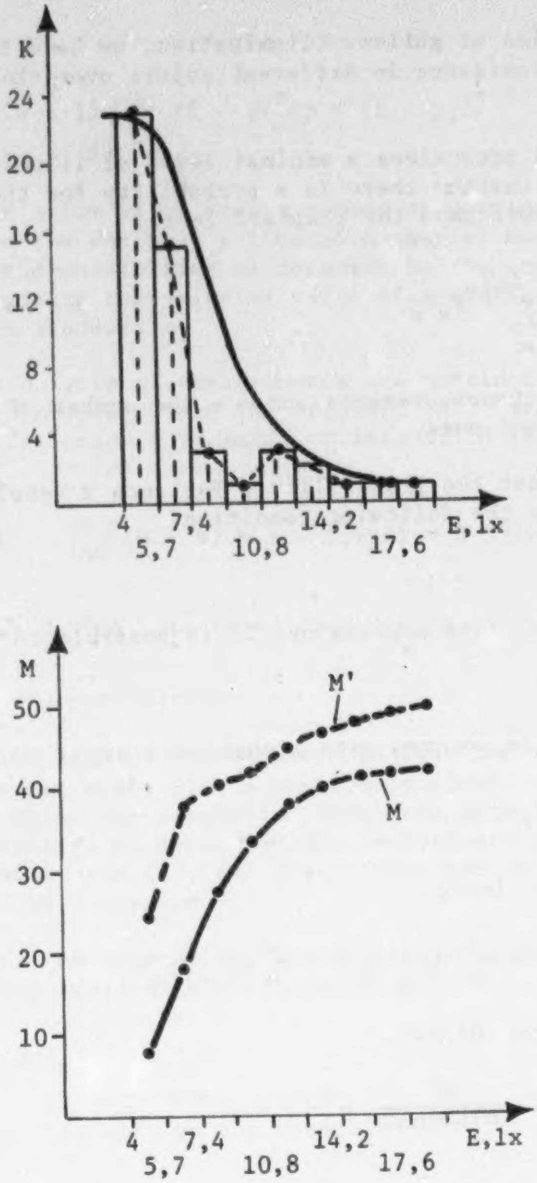


Figure 5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M'
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14,2
17,6
E,1x

Figure 6

For an estimation of gallery illumination, we have to use samples from the total sum of illuminance in different points over the whole mine territory.

As the standard prescribes a minimal level of illuminance, the task comes down to determining whether there is a probability for the random value of illuminance to be lower than the standard level:

$$P_x \leq x_{min} \leq {}_{0}\int_{o}^{x_{min}} P_x \, d\underset{x}{x} \qquad (1)$$

Let m be the number of measurements and n - the number of results with values lower than the standard ones.

Let us assume that the probability p for such a result can take a random value which satisfies the following condition:

$0 < p < 1$

After statistical data processing, it is possible to define the limits:

$p_1 \leq p \leq p_2$,

where the quantity p is located with probability of

$P_m^n \, (p_1 \leq p' \leq p_2)$, i.e.

this is the confidence level:

$$P_m^n \, (p_1 \leq p \leq p_2) = P_m^n \, (p \leq p_2) - P_m^n \, (p \leq p_1) \qquad (2)$$

After transformation we obtain:

$$P_m^P \, (n \leq N) = \sum_{n=0}^{N} \frac{m!}{n!(m-n)!} \, p^n \, (1 - p)^{m-n} \qquad (3)$$

or: $P_m^n \, (p \leq p_1) = 1 - P_{m+1}^P \, (n \leq N) = 1 - (1 - p_1)^{m+1} - (m + 1) \, p_1 \, (1 - p_1)^m \ldots$

$$\ldots + C_{m+1}^N \, P_1^N \, (1 - p_1)^{m-N+1} \qquad (4)$$

If N = 0, we can use:

$$P_m^{n=0}\ (p \leq p_1) = (m + 1)\int_0^{p_1} (1 - p)^m dp = (1 - p_1)^{m+1} \qquad (5)$$

These expressions allow us to draw a number of conclusions concerning their validity made on the basis of a limited number of measurements. That is to say, they present the possibility of determining the number of the necessary measurements by giving the relative value of deviation p and the number of deviations from the standard n.

For example: In a cycle of measurements are obtained: m = 49 with n = 9, which have a value lower than the standard one. Is the statement that the random number of deviation p is equal or less valid than 0,1 true? We put N = 9 and m = 50.

$$P_{49}^{9}(p \leq 0{,}1) = 1 - P_{50}^{0,1}(N = 9) = 1 - 0{,}9906 = 0{,}0094\ ,$$

where $P_{50}^{0,1}$ (N = 10) = 0,9906 is taken from tables.

We may investigate the opposite task.

What should be the size of the sample m so that for one or another value of the deviation m we can state with a previously given truth that from the general sum total of which the sample is taken, the relative number of deviations (i.e. the probability of deviation at one-fold measurement) is not higher than the given p_1. It is clear that by decreasing p_1 the number of measurements m should be increased.

For example, from the data of the above example we have m = 50 and n = 10 i.e. n/m = 0,2. We may state with confident probability

$$P_m^n\ (p < p_1) = 0{,}0094\ ,$$

that the real value $p < p_1$ only on the condition that

$$p_1 \approx 0 - 1{,}5\ n/m \approx 0{,}3.$$

For practical purposes it is necessary to give the value of P_1. If we accept that for a well-designed lighting installation all values obtained from the measurements of the luminance are higher than the minimum allowed level, then the decreasing of the luminance after a long-term exploitation is due mainly to the breaking down of a certain number of light sources. (It is assumed that a regular cleaning of the luminaires is done.)

If we accept that the light sources are changed when 10 percent get out of order we may determine the value of p_1.

For example, if the luminaires are located at a distance of $l = 10$ m between each other and if the broken light sources are evenly distributed, along 100 m in the gallery there will be at least one broken light source (or we may choose an area with at least one broken source). The measurements are carried out at a distance of $l/2$. It is clear that under the broken source we get luminance lower than the standard, i.e. $N = 1$. then $p < 0{,}2$ and at $P^n_m \ (p < p_1) = 0{,}9$ we get the number of the necessary measurements according to formula (4). If $N = 0$, we get formula (5).

As regards to the qualitative indices, assessment of the illumination is limited up to calculating the uniformity of the luminance and glare effect. It is expedient for calculating the uniformity to use expression

$$g_1 = \frac{E_{min}}{E_{max}} \tag{6}$$

The glare effect is calculated according to the classical methods. The measurements are carried out with a luxmetre ranging from 1-10-100 lx and an error of 10 percent, with a cosine correction of the photo receiver and corrected spectral sensitivity.

The solution of the second problem; i.e., determining the reflection characteristics of the working surfaces in underground mines, is related to perfecting the design and control of the lighting equipment. The task is brought down to determining the reflection factor, P, of the light of various mine workings, building materials, mining machines, etc., so that the design could be carried out according to illuminance of the working surface and not according to luminance. This means that both the measuring and control of the light equipment will be done according to the same parameter; i.e., illuminance of the corresponding area. This is a very handy method and presents a lot of advantages as compared to the methods of measuring luminance.

With the help of a laboratory photospectrometer, the reflection coefficients are measured at different frequences of the light for several types of coal and rock, as well as for different types of ore. The measurement of different building materials (concrete blocks, timber, etc.) is still going on. Measurements of the reflection factor of various mining machines are being prepared. When the measurements are completed, methods for design according to illuminance will be defined more exactly.

The third problem--standardization of mine lighting--is quite topical. There are many differences between the recommended levels for one and the same working place in different countries. Apparently such great differences are due to usage of different criteria and methods for determination of recommended illuminance.

A common disadvantage of all used methods is the fact that for test objects are being used plane figures--transilluminated disks, rings of Landolt, written figures, etc. What are the disadvantages of these methods?

1. The working surface is strictly fixed and the observer does not change the direction of his visual axis except in very narrow limits.
2. The test objects are equally remote from the observer and, therefore, the eye accommodation is not necessary.
3. All test objects are with equal luminance and no eye adaptational processes are taking place.

Some other disadvantages follow from ignoring the important processes accompanying the visual perception. For example, in neither of the experiments is it required to determine the form and size of the test objects--features which have great significance for the correct perception of the observed objects.

All experiments are carried out in laboratory conditions. In this way, the disturbances, such as field noise, distribution of the attention, etc., are eliminated.

How does the technological process proceed in the underground mines? Almost all operations in the mines--exploitation, loading, transportation, etc., are taking place in complicated circumstances--heavy traffic of machines and people; observation of the field operations, frequent change of the direction of the visual axis in which adaptation to different luminances is done. The presence of eye accommodation from near to far and vice versa should be particularly underlined. These two processes prolong the time of correct perception of the objects.

Essential influence on the accuracy and rapidity of the reaction of the miners exert the perception of the sizes of the objects and treat them.

According to the method and equipment described in detail in references 2, 3, and 4, the investigation for standardization of mine lighting is carried out.

As the most common criterion for visual performance capability the mean velocity of perception of visual information is taken:

$$V = \frac{H}{t}, \left[\frac{\text{bit}}{S}\right] \qquad (7)$$

where: $H = p_1 \log p_1$ is the information capacity of the visual task;
p_i is the probability for recognizing any chosen feature;
t, [s] is the time required for recognizing the test object.

Eight stereometrical solids are selected as test objects--regular prism and pyramid (trihedral, tetrahedral, and hexahedral), cone and cylinder. All solids are situated on the periphery of a circle with a diameter of 1,2 m. The visual task is to recognize three features of the test objects--shape, texture, and disposition of the test objects concerning the reference mark, situated in the centre.

The quantity of information received by recognition of different features (one, two, or three) is calculated according to formula 7 and is shown in Table 1.

TABLE 1

No.	Recognition features	Probability, p	Visual information capability H bit
1.	Shape, disposition, texture	1/32	5
2.	Shape, disposition.........	1/16	4
3.	Shape, texture............	1/16	4
4.	Disposition, texture.......	1/4	1
5.	Shape......................	1/8	3
6.	Disposition................	1/2	1
7.	Texture....................	1/2	1

While the investigations are being carried out, a reference mark appears in the visual field of the observer. At least one second after the appearance of the reference mark (that is, the time needed for the eye-accommodation of the observer), the test object appears. The time of recognition of the test object, from the moment of its appearance to the beginning of the observer's reaction, is measured.

The measurements are carried out in field conditions at different illuminances. After statistical data processing of the obtained results, which express the relation $V = f(E)$, the level of illuminance will be determined in the interval with minimal value of the velocity of visual perception, V.

The fourth problem on which considerable work has been done is creating appropriate mine-lighting equipment--luminaires, power-supply devices, safety devices, etc. It should be noted that because of the low profitableness, the production of explosion-proof luminaires is not being developed. The needs of this equipment are met through import from the USSR, Poland, Czechoslovakia, and DDR.

As a result of the expansion of mining production, a sharp need for lighting equipment is felt in the recent years. This fact called for the beginning of mine luminaire production. In the plan for mine-lighting research and development work, which goes up to 1985, the working out of luminaires for metal mines is planned to be carried out. For light sources are used fluorescent lamps and high-pressure mercury lamps. High-pressure sodium-lamps will be introduced in future. The development of floodlights and headlights for mining machines is also planned.

The basic principles accepted for the development of mining luminaires are as follows:

- The use of highly effective light sources--fluorescent lamps, high-pressure mercury, and sodium lamps.
- Ensuring safe exploitation.
- Ensuring long-term exploitation and high efficiency.
- Ensuring maximum facilities for mounting and service.

We shall consider some of the above-mentioned mine luminaire requirements.

The use of various light sources is determined mainly from the working condition and standard prescription for illumination of the working condition and standard prescription for illumination of the working places. Especially for transport and walking galleries, the workings in the stations, etc., with a height of not more than 2 to 2.5 m, most suitable are the fluorescent lamps since at high light efficiency they have considerably lower illuminance as compared with all the remaining light sources (5 to 8000 cd/m^2).

The mine-lighting recommendations TC' - 4.10 demand that the illuminance of the emitting surface should not exceed 3000 cd/m^2. It is obvious that we have to use fluorescent tubes with low wattage and apply diffusers with considerable area. These considerations are taken into account in the development of a luminaire intended for stationary lighting in underground metal mines. As a light source, two fluorescent lamps type White Light are used, each one having a power of 20W.

As a construction the luminaire is designed in such a way that the starter switch ballasts are located on the side walls of the body. In this way the surface of the reflector is kept smooth and with regular concavity so that the multiple reflections of light are decreased and the efficiency of the luminaire is increased.

At present, investigations for creating an optimal reflection surface are being carried out. The following requirements are necessary:

1. Formation of a pre-set light distribution curve.
2. Ensuring high efficiency through avoiding multiple reflections of light in the luminaire.

In order to prevent the harmful effect of mine waters and the mine atmosphere, the luminaire body is made of plastic with high mechanical strength. Thus, the corrosive effect is eliminated and the weight of the luminaire is considerably decreased, which makes it safe and suitable for mounting and exploitation.

In future, to facilitate the mounting, the input-output devices are planned to be designed with couplings.

Light nets in the underground mines in Bulgaria are supplied by light transformers with a power supply of 2 to 4 KVA. It should be noted that according to The Safety Regulations in our country, a system with isolated neutral of the transformer is applied in underground mines. That is why the voltage is transformed from 380V (660V) to 220V (127V).

All nets for voltage higher than 42V are equipped with devices for constant control of the isolation and earth-fault protection.

For connecting the light net to the power supply, manual commutation apparatuses fitted with overcurrent protection are used.

The basic co-ordinator and performer of the above-mentioned tasks is the Higher Institute of Mining and Geology in Sofia, the department of Electrification and Automation of Mine Production. In solving these problems the following subdivisions took part--the Ministry of Energy, the Ministry of Mineral Resources, the Ministry of Engineering Industry, and especially the Electrovacuum Factory in the town of Sliven and the Lighting Fitting Factory in the town of Stara Zagora.

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TITLE OF PAPER: Luminous Measurements in
Firedamp Zones of Coal Mines

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LUMINOUS MEASUREMENTS IN FIREDAMP ZONES OF COAL MINES

by

Dr. Ing Bruno Weis[1]

ABSTRACT

Mine lighting is of a great importance because of the fact that daylight is missing, that the degrees of reflection are low as well as due to the existence of large quantities of dust.

Lighting is to provide good visual conditions; it has to create a pleasant visual environment and to influence positively the safety of work.

The following expressions are good characteristics of lighting:

Illuminance
Uniformity
Luminance limitation
Direction of light and shade
Light colour and colour rendition

What can be measured are:

Illuminance (horizontal, vertical, cylindrical)
Luminance
Degrees of reflection
Screening angle
Supply voltage
Ambient temperature

The measuring accuracy is dependent on the following parameters:

Secondary normal
V (λ)-adjustment
Room evaluation
Linearity, dark burn, ambient temperature, frequency-dependence, etc.

For this application the measuring instruments have to fulfill the following:

Flameproof construction
Large measuring range (e.g., 0,001 lx to 200.000 lx)
Sturdy construction

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[1] Technical Manager, Messrs. Adolf Schuch K G, Worms am Rhein, West Germany

Battery operation (independent from the mains)
Lightweight
Small dimensions
Simple handling
Little temperature influence
Storing the measured value

In general, measurements are made because of the following reasons:

A. New equipments are checked to find out if the requirements once specified are fulfilled;

B. Equipments already in operation have to be checked in order to learn the actual condition.

The measured values of the illuminance and of the luminance may be impaired by various factors affecting the use. In such a case an adjustment has to be made.

As soon as the exact measured values are available, one must realize their presentation.

The report of measured values to be made out must comprise all important parameters of influence.

INTRODUCTION

Mine lighting is of a great importance because of the fact that daylight is missing, that the degrees of reflection are low as well as due to the existence of large quantities of dust.

Lighting is to provide good visual conditions; it has to create a pleasant visual environment and to influence positively the safety of work.

Due to the aggravated environmental conditions and because of the fact that mine gas explosions might occur, it is not easy to measure luminous quality characteristics such as illuminance or luminance. For these reasons the luminous measurements cannot be made by means of standard devices but have to be carried out with mine-gas-proof ones.

WHY ARE SUCH MEASUREMENTS MADE?

It is intended to check at the place for instance luminous project plannings. Another reason which may be the most important one is the coverage of the actual condition of an existing lighting equipment for instance in a longwall or in the gob road. After such a measurement the measured values can be compared with existing standards and regulations. If it is found out that there is no coincidence, the equipment either has to be checked or repaired; even a modification may be necessary. Another reason why such measurements of the luminous characteristics are made, may be the comparison of various equipments with the aim of finding a useful solution as far as the luminous and the economic sides are concerned.

QUANTITIES TO BE MEASURED

As to mine lighting, the quantities to be measured are resulting from the requirements stated in the special regulations, that is to say from the characteristics of quality of the underground lighting.

The most important quality characteristics are:

Lighting level
Distribution of light
Limitation of glare
Direction of light and shade
Light temperature and colour rendition

The most important quantities of luminous measurements are the illuminance and the luminance. The measurement of the degree of reflection can mostly be made outside the fiery zones.

METHODS OF MEASUREMENT

There are legal measurements and works measurements. Legal ones are generally carried out by test and surveillance authorities. They say that certain requirements with regard to the error limits of the measurements have to be fulfilled, to which further comments will be given later in this report.

Works measurements mostly serve for finding out the instantaneous status of the equipment and for comparing such values with those specified in the standards and in the regulations. The result may influence in the one or the other way cleaning the lighting fixtures, exchanging the lamps or any re-equipment and enlargement of the existing lighting equipments.

The measuring devices needed for the works measurements are subject to error limits that are considerably stronger than those of the legal measurements.

CARRYING OUT THE MEASUREMENTS

I have told you that there are two kinds of measurements.

On the one hand there is the measurement of a new equipment and on the other hand you find out the actual working condition of a lighting equipment.

It will hardly be possible to measure a new lighting equipment of a mine lighting system with the exception of a trial longwall and the like.

If, however, a new equipment is measured, you should pay attention to the lamps and the lighting fittings to be cleaned.

If electric discharge lamps are used, the light sources should be at least 100 hours old and those of the incandescent lamps should have at least 10 hours.

The measurement shall take place only if a nearly stationary position has been reached. The same refers to works measurements.

The daylight will by all means not be available.

The measurements are to be carried out only if all equipments (machines, belt conveyors, longwalls and shield-type supports) have been installed.

It is of an utmost importance - as far as low illuminances of mine lighting are concerned - to see to it that there is no shade on the light collecting area neither caused by the person making the measurement nor by the light reflecting from his clothes. Otherwise the measurement will not be correct.

All measurements shall be made at ambient temperatures predominating during the operation. If this is not possible the ambient temperature of the lighting fittings has to be considered in the evaluation.

Illuminances on roadways or certain distances are measured at a level of 0,20 m above ground.

When measuring a new equipment, in the beginning 1.25 (one and a quarter) of the nominal value are demanded.

When measuring illuminances at working places or near machines, the relevant level always has to be determined and indicated.

Also in this case the initial minimum value to be taken into consideration is 1.25 (one and a quarter) of the nominal value if the equipment is new. In case of a considerable contamination or of long maintenance intervals you should calculate with a planning factor of 1.43 to 1.67.

At the latest if the illuminance has reached 60 percent, the lighting fixtures have to be cleaned and the lamps must be exchanged respectively.

MEASURING DEVICES

In this connection above all the technical report of the TC-2.2 of CIE must be mentioned:

> Methods of Characterizing the performance of Radiometers
> (Photometers, TC-2.2, Ninth Draft, March 1980.)

Quantitative methods for the evaluation of the most important sources of errors of the photometers are described therein. For instance:

Systematic errors on the occasion of the calibration

Differences between the ideal and the real spectral distribution of the sensitivity (f_1)

Errors of the spatial evaluation as to the illuminance (f_2)

Errors of linearity (f_3)

Fatigue (f_5)

Coefficient of temperature (f_6)

For rating the influence of the less important sources of errors, special methods are suggested.

This concerns:

Reading errors (f_4)

Efforts in case of modulated radiation (f_7)

Polarization effects (f_8)

Unequal sensitivity over the receiving zone (f_9) etc.

The admissiable total error should be equal 5 percent or smaller as regards legal measurements.

It should be equal 20 percent or smaller as far as works measurements are concerned.

It is recommended that the diameter of the sensitive area of the measuring head of the illuminance meter be $\leq$ 3 cms.

The most important luminous requirements an illuminance meter has to fulfill with regard to mine lighting are:

Sufficient sensitivity

* V (λ) loyal evaluation

* for legal measurements $f_1 < 1\%$

* for works measurements $f_1 < 6\%$

* cos-loyal evaluation of the incident radiation

* for legal measurements $f_2 < 2\%$

* for works measurements $f_2 < 4\%$

The manufacturer recommends to recalibrate the illuminance meters regularly or at least every two years.

This digital luxmeter is a high accuracy device for measuring the illuminance and the mean luminance. It is particularly small and handy and has a 3-1/2 digit display with five decadicly graded measuring ranges including autoranging system. The standard range reaches from 0.01 lx (last digit) to 200 000 lx. Another version of this device has got a range from 0,001 lx to 20,000 lx.

The electrical and mechanical construction of the device which is located inside a special steel housing, is good enough to fulfill the requirements of the mine-gas and of the explosion proofness (Sch) i and (Ex) i.

There is a luminance adapter which allows finding out even mean luminances at working places and at space peripheries.

This luxmeter is equipped witha 10 mm Ø Si-photo-voltaic cell that is well adjusted to V (λ) by full filtering.

Moreover, the photovoltaic cell has got an integrated cos adaptor. Every device will be supplied with an individual test certificate for the V (λ) adaptation and the cos gradient.

The luminance adaptor has a flare angle of about 10 degres. When this accessory unit is used, the calibration of the device is automatically switched over to cd/m^2.

Furthermore the unit owns of switch for storing the measured value. There is a socket for remote controlling the value storage, thus avoiding the person in charge of the measurements to shade the measuring head.

The built-in NiCd accumulator is suitable for an operation of about 10 to 12 hours independent of the mains.

Recharging the batteries is possible in non-hazardous locations at 220V or 110V (alternating voltage) by means of a plug/cable connection. Overcharging the accumulator is impossible due to the built-in automatic charging connection. The luxmeter has got a threaded tripod bush at the bottom side of the housing. The unit is proof against water jets and corresponds to IP 54 acc. to DIN 40050.

FURTHER TECHNICAL DATA:

Resolution	:	0.05%
Absolute measuring error	:	$\leq \pm 0.5\% \pm 1$ digit against PTB standards at vertical light radiation and standard illuminant A

Deviation of linearity : ≤ 0.1% ± 1 digit

Error of consistency : ≤ 0.1% ± 1 digit

Integration time : 100 ms

Measuring rate : About 2 measurements / s

Temperature coefficient : $\alpha \leq - 0.1\% /^{\circ}C$

Operating temperature : 0° - . . . . + $60^{\circ}C$

Power consumption : < 500 mW

Built-in battery testing equipment operating time with a fully charged battery : ab. 10 to 12 hours

Quick charge of the accumulators : ab. 6 to 8 hours

Mains connection : 220 V ± 10% or 110 V ± 10% } 50 - 60 c/s.

Dimensions : H x B x T - 5.5 cm x 11.5 cm x 16.5 cm

Weight : ab. 1.5 kgs.

The absolute measuring accuracy that can be reached finally depends upon the uncertainty of the data of the secondary normal line being about 1.2%. Secondary normal lines are calibrated by national institutes. In general these are normals, normal receivers or the like which for instance are used for the calibration of measuring devices.

EVALUATION AND STATEMENT OF MEASURING RESULTS

The measured values of the illuminance and the luminance have to be converted to the agreed operating voltage of the mains. This conversion factor is given by the lamp manufacturer or can be learned from tables.

The following is valid: Converted value = $c \times \frac{U_N}{U} \times$ measured value

c = convertion factor

U_N = agreed operating voltage

U = measured value of the mains voltage

The measured results are booked either in tabular form or graphically for example in the ground plan of the longwall or of the section.

These measured values allow you to find out the following:

A. Mean illuminance $\bar{E}$

$$\bar{E} = \frac{1}{n} \times \sum_{i=1}^{n} E_i$$

i = number of the measuring point

E_i = illuminance at the measuring point i

B. Minimum illuminance E_{min}

C. Maximum illuminance E_{max}

D. Uniformity g_1

$$g_1 = E_{min} / \bar{E}$$

E. Determination of A. to D. at the individual working place.

The degree of reflection ζ can mostly be found out outside the fiery zones.

The results of a luminance measurement can be booked in tabular form or graphically as well. In this case, however, the exact observation place and the geometry of the space have to be indicated.

Detailed investigations for the evaluation of the glare are not yet available. If, however, the experience from the emergency lighting is used (DIN 5035 section 5), it will be sufficient to take the luminous intersities given by the manufacturer or to measure them and to compare them with the values of the DIN standards depending on the suspension height.

Details of the colour temperature and of the characteristics of the colour rendition can be learned from the data sheets of the lamp manufacturers.

The minutes of such measurements is to comprise the following information:

A. The exact name of the mine and of the position of the longwall or of the section or the like.

B. Names and addresses of the people who are responsible for the measurements.

C. Time at which the measurements have been carried out.

D. All details such as type and type number of the measuring device used.

E. Ground plan, if available front elevation, of the space to be measured, of the area or of the working place; measuring screen is to be indicated.

F. Exact data of the lamps and luminaires of the lighting equipment.

G. Measured results.

H. Room temperature.

I. Particularities of the measurement.

J. Comparison of the measured results and their discussion with what the DIN standards and their regulations demand.

Information whether these requirements have been fulfilled.

K. Signature, date.

TITLE OF PAPER: Reflectance Measurements
in Mining

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He is a member of the Canadian National Committee of the International Commission on Illumination and chairman of the Subcommittee on Mine Light Sources of Technical Committee 4.10 Mine Lighting of the Commission Internationale de l'Eclairage.

REFLECTANCE MEASUREMENTS IN MINING

by

Donald Trotter[1]

ABSTRACT

Regulations and guidelines for mine lighting can be expressed either in terms of illuminance or luminance. Since luminance relates to what the eye actually sees, this is becoming the preferred method. Unfortunately, however, it is the more difficult of the two concepts to work with, The illuminance put out by a source is known from the manufacturer's isolux and isocandela diagrams and luminance can be calculated if the surface reflectance is known. Accurate measurements of reflectance then provide the missing link for good lighting design. Measuring methods for reflectance are described and results of measurements on selected working longwall faces are presented.

INTRODUCTION

The International Commission on Illumination (C.I.E.) is an organization of 29 countries devoted to international co-operation on all matters relating to the art and science of lighting. One of its objectives is to provide guidance in the application of the basic principles and procedures to the development of international and national standards in the field of lighting. This work is carried on by 26 Technical Committees, each of which is assigned to a member country. The reports and guides developed by these international committees are possible only through an organization such as the C.I.E. and are accepted throughout the world.

Technical Committee 4.10 of the C.I.E. is involved solely with mine lighting with delegates appointed from 19 of the member countries. At the last annual meeting of this committee, held in Katowice, Poland in April 1980 several important decisions were made on the preferred method of specifying mine lighting standards for underground coal mines. These standards are not binding on the member countries but act as important guidelines for the various countries as they struggle to establish their own individual standards.

The following is a summary of the more important guidelines.

1. Luminance levels should be specified rather than illuminance levels.
2. Minimum luminance is dependent on the nature of the task and the working conditions.

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[1] Associate Professor, McGill University, Montreal Canada, Department of Mining and Metallurgical Engineering

(a)	where traffic is light and mechanization is minimal but general lighting is desirable because of safety considerations	0,05 $\mathrm{cd \cdot m^{-2}}$
(b)	where mechanized equipment normally operates	0,2 $\mathrm{cd \cdot m^{-2}}$
(c)	underground chambers where precision work is not performed	10 $\mathrm{cd \cdot m^{-2}}$
(d)	underground chambers where precision work is being carried out	20 $\mathrm{cd \cdot m^{-2}}$

3. The luminance in the visual field of a miner should not change more than five times in a distance of 1 m, measured along the area being observed, provided that the reflectance in this observed area does not change either. In other areas the uniformity of luminance should be no more than 10:1.

4. Values under 3000 $\mathrm{cd \cdot m^{-2}}$ in a miner's visual field are acceptable as a permissible luminance of light sources used for network illumination. In headings and other workings, luminaires giving values greater than 3000 $\mathrm{cd \cdot m^{-2}}$ can be used provided they are placed above the line of vision. In horizontal workings this is taken as a minimum height of 2,5 m from the floor to the centre-line of the source.

PRESENT WORLD PRACTISE

No two countries seem to be able to agree on how to specify mine lighting standards for coal mines but they can be lumped into four distinct groups.

GROUP 1 - Countries which specify minimum standards of illuminance based on the location in the mine, e.g. Belgium, Czechoslovakia, Federal Republic of Germany, Hungary, Poland.

GROUP 2 - Countries which do not specify minimum standards of illuminance but publish recommended minimum values of illuminance as suggestions for the mining industry, e.g. United Kingdom.

GROUP 3 - Countries which specify neither minimum standards nor recommended values. Where lighting is required it must be 'sufficient' or 'suitable' e.g. Australia, Canada.

GROUP 4 - Countries which specify minimum standards of luminance based on the location in the mine, similar to the recommended guidelines of the C.I.E. e.g. United States.

PRESENT U.S. PRACTISE

The United States is the only country which can be placed in Group 4 at the time of writing (Oct. 81) and it has the most stringent mine lighting standards of any country. The standards have been the subject of many papers (3,5,9) and will not be dealt with other than to mention that three important concepts were recognized.

(1) Luminance was to be used as the measuring criteria. Theoretically this allows flexibility in design to take into account the variation in reflectance found in the real world.

(2) The standards required much more than task lighting. Peripheral vision was thus recognized as being important for the safety of miners.

(3) The maintenance of a minimum level of luminance ensures that adaptation problems will not be severe.

In practise, however, the reflectance is not measured for each installation. The illuminance of the light sources are evaluated from photometric data obtained in an illumination laboratory of an equipment manufacturer or in the illumination laboratory here at Beckley. The luminance is then calculated by assuming a coal reflectance of 0,04 and also assuming a planning factor of 1,3. There is a built in danger to this method in terms of excess cost and harmful glare if the assumed reflectance is much less than the actual reflectance. As well, manufacturers tended to over-design so that their equipment would be in compliance in any mining situation. As a matter of fact, assumed reflectance was previously lower than 0,04 but was raised to its present value largely to help alleviate operator complaints about glare.

The U.S. standard converts to 0,2 $cd \cdot m^{-2}$ in SI units. This is the value recommended by the C.I.E. to be the minimum luminance level where mechanized equipment normally operates. Comparisons with Group 1 countries are difficult since standards are stated in illuminance rather than luminance. Assuming a diffuse reflectance of 0,05, then an illuminance of 15 lx would produce a luminance of around 0,2 $cd \cdot m^{-2}$. Values around 15 lx occur in the standards of several countries so there appears to be general world-wide agreement on the required lighting levels.

REFLECTANCE THEORY

Good underground lighting design is not possible without a knowledge of reflectance. Not only do we see by reflected light but in an underground mine that portion of reflected light which does enter the eye is usually only a small percentage of the light that struck the object being observed. The majority of the light is absorbed by the surface. Measurements of this phenomena are required so that the lighting installation can compensate for the loss or the surface can be modified to cut down on absorption.

Reflectance (ρ) can be thought of as a measure of the efficiency of a surface in retransmitting light. If $\rho = 1,00$ then the surface reflects all the light and if $\rho = 0,00$ all the light is absorbed. Natural surfaces have reflectances somewhere between these extremes. In practice nearly all surfaces are a combination of diffuse and specular reflection. Reflectance can then vary over a considerable range of values or stay fairly constant for the same material. If reflectance stays constant, surfaces appear equally bright when viewed from any direction. For most surfaces, brightness is greater when the viewing angle is close to the angle of incidence. Various types of reflectance are illustrated in Figure 1 with the arrows having a vector connotation. The top left diagram illustrates specular reflectance and is the type one obtains from a shiny metal surface or a mirror surface. The top right diagram shows specular diffuse reflectance where most of the light is reflected specularly but there is a slight diffuse component. Gloss and semigloss paints reflect light in this manner. Diffuse specular reflectance is illustrated in the lower left diagram and completely diffuse reflectance in the lower right diagram. In a dry mine, most surfaces exhibit diffuse specular reflectance but a very dusty or powdery surface would come close to exhibiting completely diffuse reflectance.

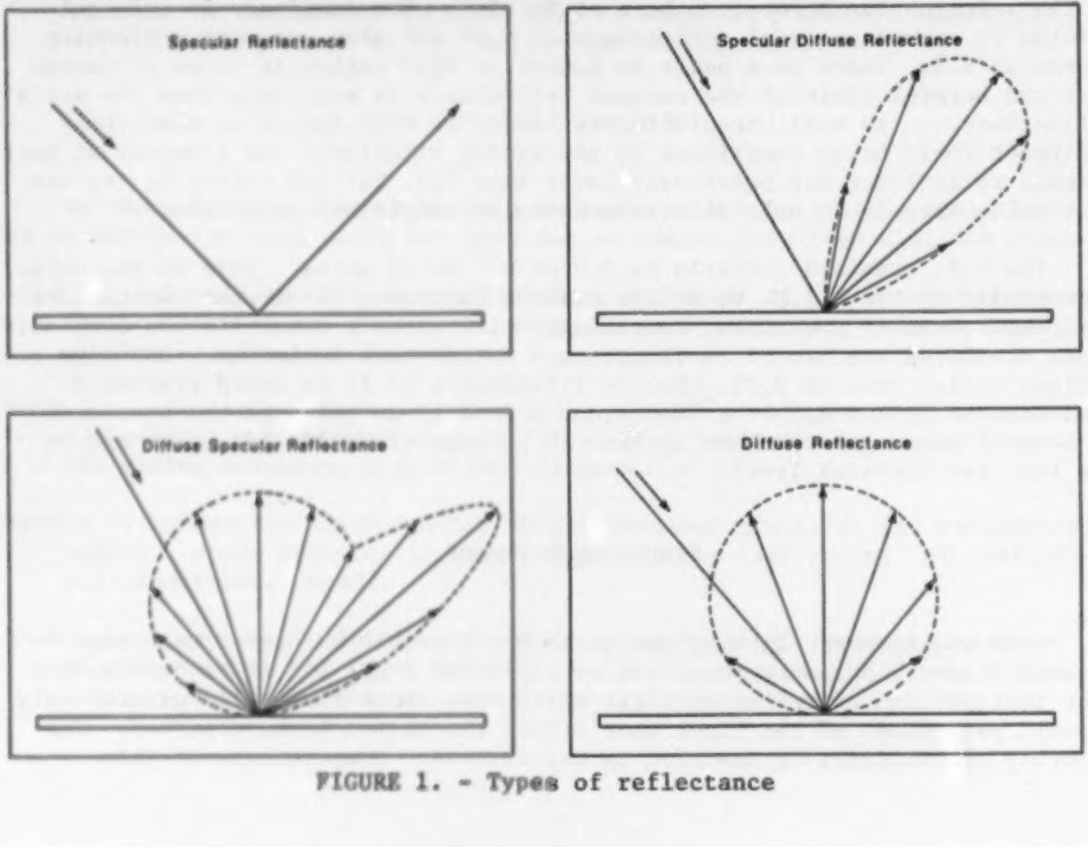

FIGURE 1. - Types of reflectance

The figures shown are an oversimplification of what actually takes place since only one ray of incident light is shown. A cone of light could strike the surface, or the incident light could be arriving from all directions. Similarly, one could attempt to measure the reflected light in only one direction, could measure a bundle of the reflected rays of light, or could measure all of the reflected light. This means there are three geometrical conditions for both the incident and collected fluxes: hemispherical, conical and directional. Using the various combinations it is possible to have nine kinds of reflectance measurements: (1) bi-hemispherical; (2) hemispherical-conical; (3) hemispherical-directional; (4) conical-hemispherical; (5) bi-conical; (6) conical-directional; (7) directional-hemispherical; (8) directional-conical; (9) bi-directional. Angles of incidence and of recording as well as the solid angles should be specified if accurate reflectance measurements are being made.

The incident angle is specified first, and then the recording angle. When the solid angles are not specified the assumption is made that they are infinitesimal which means the reflectance would not change if they were made smaller. With textured surfaces the orientation of the surface may be important. A ribbed surface may have different reflectances depending on whether the incident light strikes it along the axis of the ribs or at right angles to the ribs. Similarly a flat surface can give different reflectances depending on the angle at which it is tilted. It is important to measure this tilt angle when the incident and recorded light path and the normal to the surface do not all lie in the same plane. It may also be important to specify the type of light that strikes the surface. When all other parameters are held constant, reflectance varies with the illuminating wavelength.

UNDERGROUND REFLECTANCE MEASUREMENTS

Four different techniques have been employed by McGill University researchers. These are:

(1) reflected-incident light comparison

(2) standard chips comparison

(3) reflectance standard comparison

(4) sphere reflectometry

The first technique is the easiest but is the least accurate. The second method gives an approximate reflectance value which is usually sufficient for design work. The third method is tedious but more accurate. The fourth method is the most accurate but requires special equipment.

(1) Reflected-Incident Light Comparison

The method is useful in determining the reflectance of diffuse surfaces. A small box-shaped lux meter is placed against the surface to be measured and then drawn back about 0,1 m to avoid shadows. A reading of the illuminance given off by the surface is recorded. The meter is then turned around and held against the surface and a reading of the illuminance is recorded. When this type of lux meter is used, the meter dial should face up to prevent any error that might result from unbalance of the microammeter. The reflectance ρ can be determined from

$$\rho = \frac{E_1}{E_2}$$

where ρ = reflectance

E_1 = illuminance emitted from surface whose reflectance is required

E_2 = illuminance striking the surface under test

Some problems arise with the method. If the same lux meter measured the light reflected from a surface and is then turned around to measure the illuminance from a source, it has to be assumed that the reflectance is completely diffuse. Although the operator is careful that shadows do not fall on the face of the cell, he is blocking light which would otherwise reach the surface, so that instrument accuracy may suffer.

(2) Standard Chips Comparison

A very simple method is available to determine the approximate reflectance of a surface(8). Chips of various known reflectances can be purchased from the Munsell Color Company or can be made up from commonly encountered surfaces. After the sample is selected whose reflectance is required, the chip that appears closest in brightness to the sample is compared to the sample surface, being careful to mask out surrounding surfaces. For most accurate results, the mask should have a reflectance close to that of the unknown surface. The neutral matte chips are arranged in the following pattern of reflectance (Figure 2).

0,025	0,031	0,038	0,046	0,055	0,066
0,066	0,077	0,090	0,104	0,120	0,137

The chips do not increment uniformly in reflectance but are designed so that the changes in greyness appear to the eye to occur in uniform steps. The 0,066 chip is repeated in the second row to facilitate easy matching. Figure 2 shows a match being attempted for a surface with a reflectance close to 0,012.

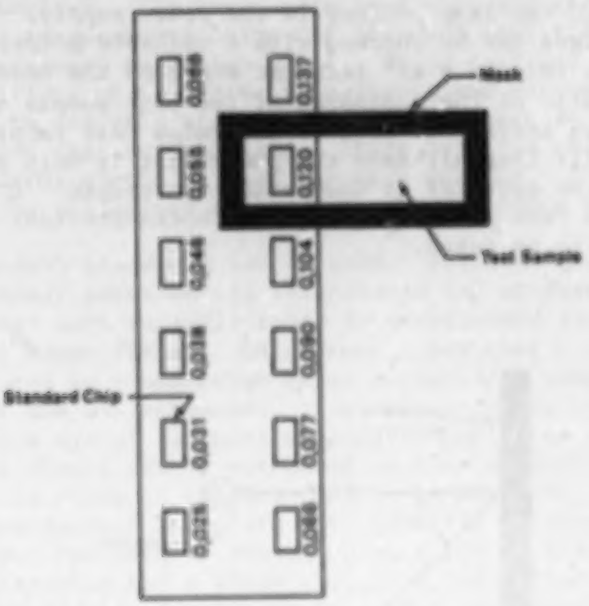

FIGURE 2. - Reflectance by chip comparison

An estimate can be made of the reflectance of the sample by comparing it to the known reflectance values of the two chips that appear closest in brightness. The mask is large enough that the two chips and the surface can all be compared at the same time.

It is important that the comparison method be done using the same type of light source that will be installed in the working place. For example, the reflectance of a yellow rock surface will be higher under sodium light than it will under an incandescent light. Strongly coloured rocks or other surfaces show the greatest changes in reflectance with different source types. For neutral greys, there is little change in reflectance using different types of lights.

(3) Reflectance Standard Comparison

This method is more accurate but takes more time. When possible, specimens can be gathered so that reflectance measurements can be performed in a laboratory where conditions are more accurately controlled. When it is not possible to remove a test surface or when it is felt that by removing the surface the light properties would be modified, measurements are conducted in the field. The measurement of reflectance in a mine is often difficult because of time limitations and the variety of surface structures and conditions. Hence, it is not possible to make complete measurements with the same accuracy as in the laboratory. For these reasons, field reflectance values are approximations obtained using abbreviated measurement techniques. When the light source can be controlled, a miner's cap lamp mounted on a tripod serves as the source, and a common cap lamp battery is the power supply. Lumen depreciation due to battery fatigue can be checked with a suitable meter. The light source is positioned so as to give a 45° incident angle on the test sample surface (Figure 3). The ratio of the luminance of the test sample surface to the luminance of a known surface is used to determine test sample reflectance. Typically on an unlit longwall face the photometer is held about 1,5 m from the coal face and the operator is underneath the chocks. A source held about 0,7 m from the coal face at the edge of the chocks provides sufficient luminance for readings to be taken.

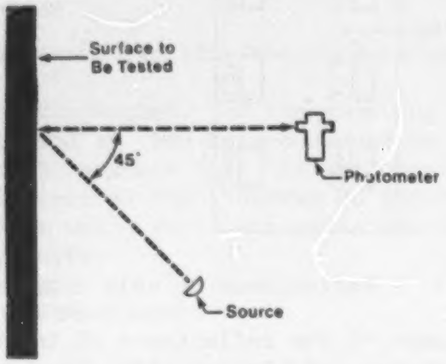

FIGURE 3. - Geometry for reflectance standard comparison

Luminance measurements are made on the surface to be tested and on a standard surface of known reflectance which is mounted on top of the surface under test. The reflectance of the surface under test is

$$\rho = \rho_s \frac{L}{L_s}$$

where

ρ = reflectance of surface to be tested

ρ_s = reflectance of standard surface

L = luminance of surface to be tested

L_s = luminance measured off standard surface

CIE standard conditions for reflectance measurements state "for the illuminator, illumination shall be within five degrees of, and centred about, a direction of 45 degrees from the perpendicular to the test surface. The area of the illuminated spot should be not less than that of a circle seven centimeters in diameter. Viewing should be within ±5 degrees of, and centred about the perpendicular". The basic reference standard for 45-degree, 0-degree reflectance measurements using CIE standard conditions is a pressed layer of freshly prepared magnesium oxide. It is assigned a reflectance of 1,00 for the conditions of 45-degree illuminance and perpendicular view. It is not convenient to use this standard underground because of preparation time and the large number that are required. Since the mine atmosphere is usually dusty, fresh standards should be used for each reading. Fortunately secondary standards can be calibrated relative to the reference standard.

Various secondary standards can be used. Porcelain-enameled metal plaques are reasonably permanent in reflectance and uniform over the surface. Hitchcock(5), in his work on reflectance in underground coal mines, used "Millipore" Filter Paper #29325. This paper approached a lambertian surface and has been compared to a magnesium oxide surface for every possible geometric condition of the reflectometer. Its only drawback is cost. Munsell Color Company sell a set of 32 chips ranging in reflectance from 0,025 to 0,900. Individual sheets can be purchased so that a secondary standard can be obtained which is close to the material to be measured. A good secondary standard is a Kodak Neutral Test Card Cat. 1527795, designed primarily for colour photography. The card is about 200 mm x 250 in size, and has a grey side of 0,179 reflectance and a white side of 0,900 reflectance in the $45^{o}/0^{o}$ position. The grey side in particular is useful in mine work because of its low cost, its guaranteed uniformity from card to card, its thickness which allows easy mounting, and because its reflectance often closely approximates that of underground surfaces. This latter feature is important since brightness matches can be made quickly when using visual photometry methods.

In practise the cards can be cut into four and individually placed in plastic bags sealed with tape to protect them from moisture and dust. Cards are fastened onto the surface to be measured by placing caulking compound from a gun and cartridge onto the white side and pressing the card firmly into place. Cards are normally destroyed after one use, since humidity, dust or dirt might affect their light reflecting properties.

Measurements are made to determine reflectances of various mine surfaces with the photometer either hand-held or tripod mounted. The observer must be close enough to keep the object completely in the viewer. The record angle, which is between the axis of the telescope and an axis vertical to the test plate, and the incident angle, which is between the axis vertical to the test plate and the light source, should be recorded. On structured surfaces the tilt angle, which is between the plane of the surface being measured and the plane formed by the incident beam and the recording line of sight is also measured. The method assumes diffuse reflectance and surfaces should appear diffuse to the eye. Table 1 shows field measurements taken from coal mines in the Sydney area of Nova Scotia in Canada using a J-15 photometer [MSA 39762](3).

Mine	Seam	Location	Mining Method	No.of Rdgs.	Dist. Bet. Rdgs. (m)	Hgt. of Rdgs. (m)	Mean ρ	Std. σ	Ambient Conditions
Prince	Hub	1-E Wall	Retr. Short Longwall	4	12,2	1,7	0,058	0,005	Readings every 10 chocks from #10. Rough walls. Bedding not visible. Clean, very dry coal surface.
#26	Harbour	13-S Wall	Adv. Longwall	14	15,3	1,5	0,042	0,011	Readings at chocks 5,12,16 and every 10 to #126. Clean, dry smooth coal surface. Bedding well defined. Lights 4th chocks.
Lingan	Harbour	7-E Wall	Adv. Longwall	13	15,3	1,5	0,035	0,011	Readings every 10 chocks from #7 to #127. Varied wet and dry. Varied clean, dusty and very dusty.
Prince	Hub	2-E Wall	Ret, Short Longwall	6	Varied	1,5	0,043	0,009	Readings every 10 chocks from #15 to 45 plus 53 and 56. Rough face, bedding not visible, dusty, wet.

TABLE 1. - Underground reflectance measurements. 45%° bi-directional

Off Angle	-70	-60	-50	-40	-30	-20	0	10	20	30	40	50	60	70
ρ Dry	0,018	0,023	0,027	0,036	0,048	0,070	-	0,126	0,053	0,034	0,025	0,022	0,021	0,019
ρ Wet	0,011	0,016	0,019	0,026	0,035	0,053	-	0,161	0,060	0,034	0,023	0,021	0,019	0,018

Description: rough surface, slight bedding, calcite present, slightly dusty, 2360K tungsten source. Prince Mine, Hub seam, 2-E wall.

TABLE 2. - Laboratory gonioreflectance measurements, sample #35

(4) Sphere Reflectometry

Sphere reflectometry provides a method of taking bi-hemispherical reflectance measurements. In this technique, all flux reflected in 2π steradians is included in the measurement, using a device called a sphere reflectometer. This is a receptor which is an integrating sphere having a flat circular aperture and is placed over the surface to be measured. Normal mine lighting design practise does not require such a refined technique.

LABORATORY GONIOREFLECTANCE MEASUREMENTS

The reflectance standard comparison method can be used in a photometric laboratory to measure how the reflectance of different surfaces varies with the incident angle and the viewing angle for bi-directional conditions. Since there is an infinite number of geometric conditions, incident angle is usually held to 0°. Zero degree incidence is the most important angle since a cap lamp, headlights on a jumbo, etc. are generally shone directly rather than obliquely onto the surface to be viewed.

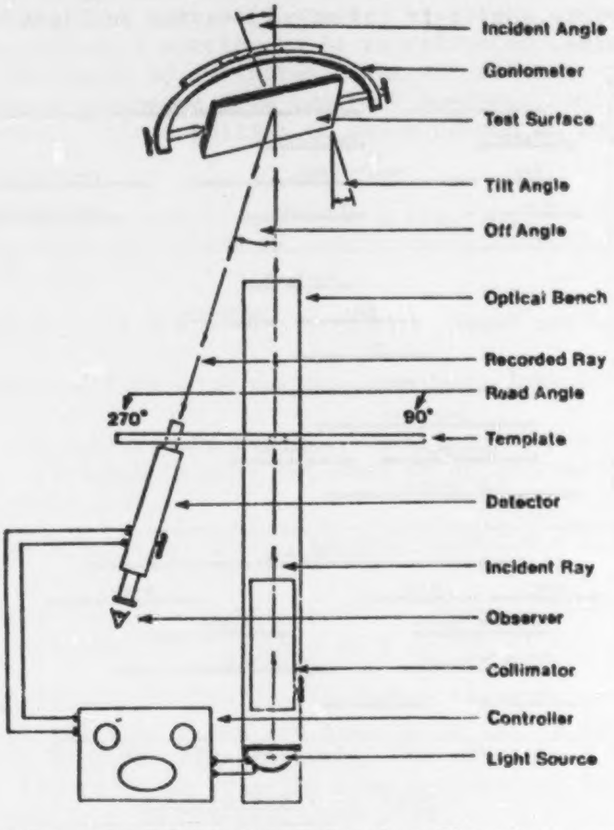
Incident Angle
Goniometer
Test Surface
Tilt Angle
Off Angle
Optical Bench
Recorded Ray
Road Angle
270°
90°
Template
Detector
Incident Ray
Observer
Collimator
Controller
Light Source

FIGURE 4. - Plan view of bi-directional reflectance measurement

The position of the detector is located with respect to the light source. This location is defined by the OFF ANGLE which signifies the angle between the detector and the light source, and the READ ANGLE which denotes the polar position of the detector around the light beam, with the 0^{o} position corresponding to the zenith. Azimuth angles are then read as one faces the specimen under study. With test surfaces mounted on the goniometer the beam of incident light could be moved through a horizontal plane perpendicular to the surface measured. This is the INCIDENT ANGLE. The specimen could also be rotated about a vertical plane, and is recorded as the TILT ANGLE. When measuring a non-ordered surface, the tilt becomes meaningless and is not recorded. The complete geometry of a bi-directional reflectance measurement, as illustrated in Figure 4, includes (1) incident angle, (2) off angle, (3) read angle, (4) tilt angle, and (5) colour temperature. Figure 5 summarizes the results of many hours of laboratory experiments to determine reflectances of substances. Materials plotted to the left of the chart tend to soak up light, while those occurring to the right are more easily seen since not too much light is trapped. The longer the length of the bar, the more specular the surface tends to be or the more varied the results are from different samples of the same substance. A comparison of the reflectance values for coal and magnesite will help the reader to appreciate why it is infinitely easier to light the working face of a magnesite mine.

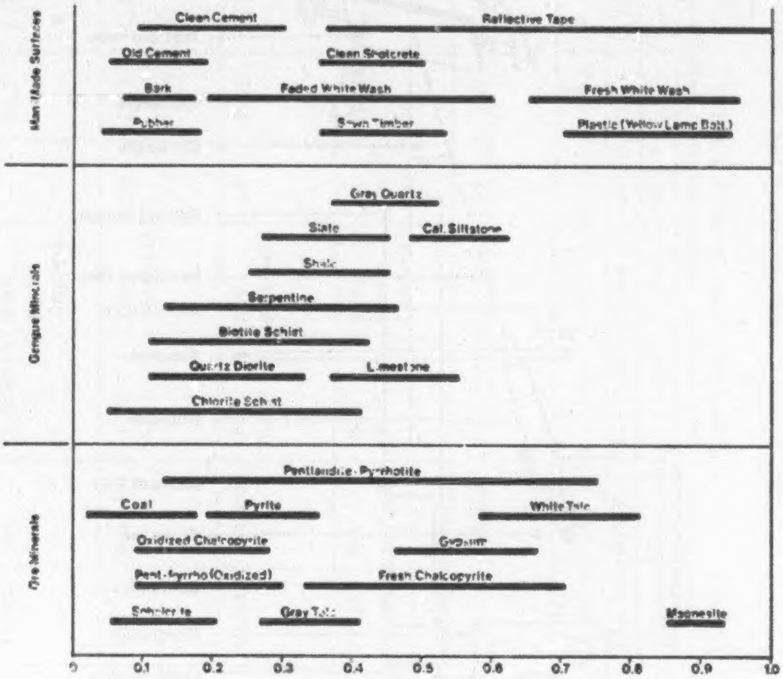

FIGURE 5. - Reflectance

LUMINANCE CALCULATIONS

The illuminance distribution of a luminaire is obtainable from the manufacturer. One should verify, however, that the values have been obtained by a well-known independent testing laboratory. The reflectance can be determined by methods outlined in the previous section. Expected luminance values can then be calculated.

$$L = \frac{\rho E}{\pi}$$

where L = luminance in $cd \cdot m^{-2}$
ρ = reflectance (dimensionless)
E = illuminance in lux

Luminance takes into account the light which actually leaves a surface and consequently gives us the subjective sensation of brightness and contrast.

When a lamp is used to light a mine opening, the light falling on the floor, walls, and ceilings causes these surfaces to act as light sources, but only a portion of the light gets reflected. This light, on striking floor, walls and ceilings, allows a portion to be re-reflected and the process of inter-reflections continues ad infinitum. The net effect could be that the total number of lumens projected from the rock surfaces could exceed the lumens put out by the source. This condition is quite common in confined spaces with high reflectances.

If the uniform reflectance of the rock surfaces is ρ and a luminaire is giving of Φ lumens, then the number of lumens being emitted from the rock surfaces is given by $\Phi\rho\ (1 + \rho + \rho^2 + \ldots + \rho^\infty)$.

Since $\rho < 1$, the series $1 + \rho + \rho^2 + \ldots$ can be summed and equals $(1 - \rho)^{-1}$

The total lumens emitted from rock surfaces is then given by $\Phi\rho/1 - \rho$

To illustrate, if the reflectance was 0.2, then total lumens would be $0,2\Phi/0.8 = 0,25\ \Phi$. Although this is not much of an increase, notice what happens for higher values of ρ.

For a reflectance of 0,6, total lumens becomes $0,6\Phi/0,4 = 1,5\Phi$.

The theory shows that by changing rock reflectance from 0,2 to 0,6 (a factor of 3), the available light alters by a factor of 6.

In practise, measured results are less than this, as some of the light gets absorbed by the atmosphere and the area being lit is not completely enclosed, causing some light to escape through the openings. Nevertheless, the theory illustrates the value of treating mine surfaces of low reflectance to get much greater benefit from the available light.

The theory also shows that for mine surfaces with reflectances below about 0,2 then the added benefit of light achieved by inter-reflections is not enough to affect calculations. Above 0,2, the designer may want to take into account the additional light available due to inter-reflections.

The luminance falling at a point on the floor can be expressed as

$$L = \frac{I_\theta \cdot \cos^3\theta \cdot \rho \cdot Ab}{h^2 \cdot \pi \cdot (1-\rho)}$$

where I_θ = the intensity in candelas from the source to the point of measurement

θ = the angle between the vertical and a line from the source to the point of measurement.

ρ = reflectance

Ab = absorption factor

h = the mounting height in metres

Where rock reflectances are low, the Ab term and the $(1-\rho)$ term will be very close to each other and to all intents and purposes will cancel each other out. The formula can then be simplified to

$$\boxed{L = \frac{I_\theta \cdot \cos^3\theta \cdot \rho}{h^2 \cdot \pi}}$$

Similar formulas can be used to determine wall luminance or back luminance and are extremely useful in determining lamp spacing. For practical reasons, lamps should be spaced far apart to keep capital costs down, but the level of luminance should not fall below some predetermined value established in a standard or in a guideline. The formula is also useful in determining the uniformity of luminance between lamps to make sure that hot spots do not occur.

SOME OBSERVATIONS

These observations are based on underground reflectance measurements of coal classified as volatile class A bituminous at three mines in the Sydney-Glace Bay area of Nova Scotia, and on laboratory studies of several selected samples of coal taken from two working seams at these mines.

- Based on bi-directional $45^{o}/0^{o}$ underground measurements, the 0,04 design value for coal reflectance currently in vogue in the U.S.A. is a good design value (Table 1).
- Laboratory measurements of reflectance tend to be lower than field measurements for the same bi-directional geometry.
- Measurements on dry longwall faces exhibit a smaller standard deviation than wet longwall faces on the same seam.
- Longwall faces dry rapidly after the passage of the shearer drum.
- Gonioreflectance measurements in the laboratory display a high standard deviation for both dry and wet samples (Table 2). Lowest recorded value was 0,011 and highest was 0,16.
- Highest gonioreflectance readings are obtained when the viewing angle is close to normal to the coal face i.e. coal exhibits specular diffuse reflectance.
- Hemispherical-conical reflectance measurements exhibit a low standard of deviation as the viewing angle is changed.

CONCLUSION

Very little information is available in the literature on reflectance measurements in coal mines. If luminance is to be the governing criteria for standards and guidelines, then more research is required into the reflectance of underground coal seams. The 0,04 reflectance value so commonly employed is certainly a good design value for many situations but could be a poor choice for many other situations.

Lord Kelvin expressed the problem in these words: "When you can measure what you are speaking about, you know something about it. When you cannot express it in numbers, your knowledge is of a meagre unsatisfactory kind; although you may have the beginnings of knowledge, you have scarcely in your thoughts advanced to the stage of a science".

Since the CIE has stipulated that luminance is the preferred method, a uniform method of measuring reflectance is required. The method should be simple and relate to the real world. One suggestion is to use hemispherical-directional reflectance measurements, that the direction be at right angles to the coal face, and that the acceptance angle of the photometer be set between about 10 degrees and 15 degrees. This would most closely duplicate a longwall face illuminated with an almost continuous string of intrinsically safe luminaires, which is fast becoming the most common method of coal mining throughout the world (Figure 6).

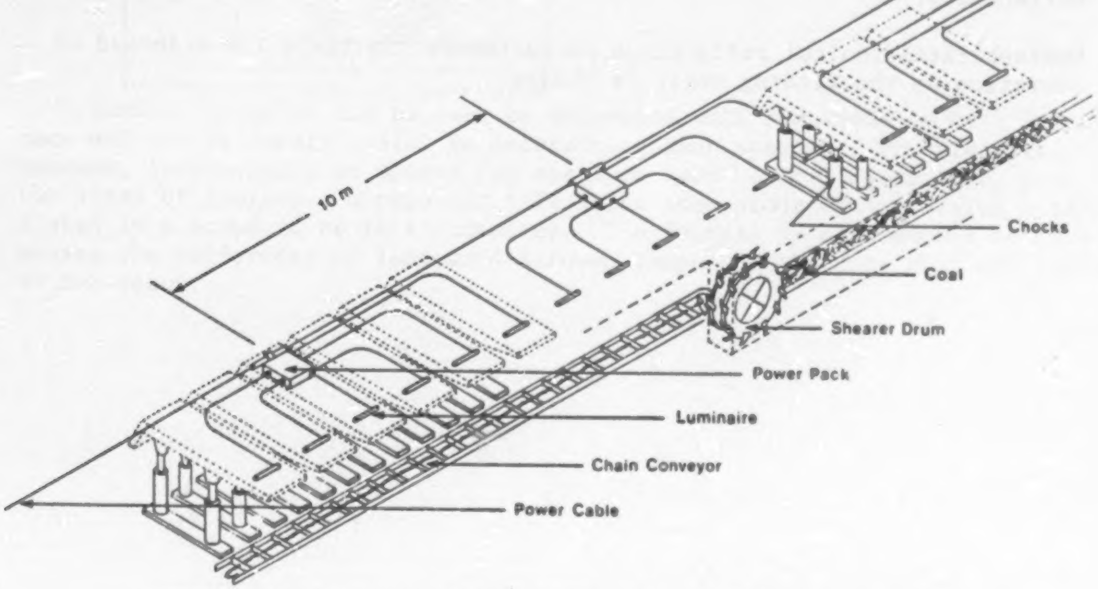

FIGURE 6. - Method of lighting a longwall face

A common reporting method for the lighting situation depicted would allow comparisons to be made among coal seams throughout the world, perhaps leading to a classification system of coal seams for luminaire design.

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TITLE OF PAPER: Visual Attention Locations
and a Methodology for Assessing Visibility from Underground
Mining Equipment

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VISUAL ATTENTION LOCATIONS AND A METHODOLOGY FOR ASSESSING VISIBILITY FROM UNDERGROUND MINING EQUIPMENT

by

Mark S. Sanders, Ph. D.,[1] James Peay,[2] and Thomas Bobick[3]

ABSTRACT

A task analytic approach was used to define information requirements and visual features which served as sources of information for operations of continuous miners, shuttle cars and scoops. Information requirements were prioritized and the location of visual features determined. From this analysis, visual attention locations, containing one or more important visual features, were identified. A total of 74, 54, and 54 visual attention locations were developed for continuous miners, shuttle cars and scoops respectively.

A procedure was developed for assessing whether operators in existing machines could be expected to see the visual attention locations. The procedure makes use of a Human Eye Reference Measurement Instrument (HERMI) designed for this project and an outside-in-photographic procedure. A sample of continuous miners, shuttle cars and scoops were used to test the procedure. Illustrative results are presented.

INTRODUCTION

This research was carried out under Contract J0387213 awarded to Canyon Research Group, Inc., by the Bureau of Mines, Pittsburgh Research Center, Bruceton, PA. The primary purpose of this effort was to determine the visibility requirements for shuttle car and continuous miner operators. Scoops were considered, insofar as they fulfill functions in the mine similar to those carried out by shuttle cars (i.e., loading, transporting, and unloading of coal). A secondary objective was to evaluate the actual field of visibility for a sample of machines. The purpose of this latter evaluation was to develop a simple procedure for visibility evaluation of mobile equipment.

DETERMINING WHAT NEEDS TO BE SEEN

It is important to distinguish visibility requirements; i.e., what needs to be seen, from fields of visibility; i.e., what can be seen. Determining what operators need to see in order to perform their job efficiently and safely can only be determined by observing operators performing the task and by interviewing them. Fields of visibility, on the other hand, can be assessed objectively and independent of the operator by recording what actually can be seen from the operator's position.

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The observation and interview approach was used in this project to determine what needs to be seen while operating equipment. A total of twelve mines were visited. A total of 28 working sections were observed and approximately 100 operators interviewed. Operators with varied degrees of experience were interviewed. No systematic differences in visual requirements were noted between novice and experienced operators.

A problem typically encountered in determining visibility requirements was evident in the operators' responses. When asked what they needed to see, most operators responded in terms of what they could see. The logic being that they do their job effectively and safely and if they cannot see a particular feature, therefore, it is not necessary to see it. This problem was somewhat overcome by using a task analytic approach in the interviews.

Using a task analytic approach, the job was divided into tasks, e.g., loading, tramming, unloading. For each task, the operator was asked what information is required to do the job, e.g., position of shuttle car relative to the tail boom of the continuous miner, location of obstacles in the roadway, position of shuttle car in roadway; information requirements being global in nature. For each information requirement, specific visual features which serve as sources of that information were then identified.

The importance of each visual feature was determined by rating the importance of each information requirement in terms of safety and productivity. The location of each visual feature in the visual field was determined. From this information, visual attention locations, where one or more visual features are located, were identified.

The two unique features of this approach are the pivotal function played by information requirements, and the system for specifying the location of the visual features and visual attention locations.

Information requirements are broad categories of information that the equipment operator needs in order to operate the equipment safely and efficiently. The types of information that are relevant to our purposes are those that relate to the interface between the machine and the mine environment. We are not concerned with the stored knowledge required to operate the equipment such as the function of the various controls on the machine. We are concerned with information that changes as a function of time or location within the mine and for which the visual sense is a significant source.

There are usually multiple sources of information available to satisfy any given information requirement. In some cases, redundant sources exist, in other cases, several individual sources must be combined in order to satisfy the requirement. Not all sources of information are visual; some are auditory and others are tactual. Our concern, of course, is with the visual features that serve as sources of information. Usually, operators are not aware of how they get the information, only that they become aware of it. The operators, in essence, build a cognitive structure or pattern of phenomena which is so integrated that it constitutes a functional unit whose properties are more than the sum of the parts (i.e., a cognitive gestalt). When we attempt to dissect this gestalt into its parts, we lose some of its essential character. Nevertheless, in order to develop visual requirements, specific visual features must be identified which serve as the sources of the information required to safely and efficiently operate the equipment.

The location of a visual feature can be specified by its position in three planes: fore-aft, lateral or side-to-side, and vertical or up-down. To do this, however, requires that reference points in each plane be identified. Ideally, the reference points, and hence the location of the visual feature should be so determined that they can be generalized across specific equipment configurations. For example, a continuous mining operator needs to see the cutting head of his machine. If the fore-aft location were specified with reference to the operator's head position, the location of the cutting head would vary depending on the length of the machine and the location of the operator's compartment. However, if the fore-aft position is specified with reference to a machine point, in this case the front edge, it does not matter what the length of the machine is or where the operator is positioned.

Specifying the location of visual features, even with the use of generalizable reference points, requires that specific assumptions be made about the size of the equipment, how the equipment will be used, where it will be used, and most importantly, when or where the visual feature should be seen. We will address this last point since it is central to our approach.

The philosophy underlying the specification of visual feature locations is that the location specified should represent the last point at which the information, if received, can be used by the operator. An example will clarify this. Consider a road obstruction such as a pile of timber, and its location in the fore-aft plane. How far in front of the vehicle must the operator be able to see the obstruction? If he can see the pile 200 feet ahead, that would be nice, but it is not really necessary. The location where he must be able to see it is a necessary stopping distance ahead of the machine. This necessary stopping distance is a function of the speed of the machine, the reaction time of the operator, and the inherent stopping capability of the machine.

Specifying the location of in-mine visual features requires assumptions to be made regarding how the equipment is being used and the geometry of the mine roadways. Unless some simplifying assumptions are made, visibility requirements will be different for each mine, or area within a mine. It would be ludicrous to demand manufacturers to design their equipment to match the specific size and use characteristics of a mine. It would not be cost effective. To overcome this, simplifying assumptions were made concerning the equipment, its use, and mine conditions. These assumptions were based on underground observations of equipment, interviews with operators, and review of equipment dimensions. They are representative of the vast majority of mining situations.

There are two approaches for specifying the location of visual attention locations. The first is to specify "visual windows" of given size and location. The second approach is to specify specific points in space which must be visible. Visual windows are defined as areas of unobstructed vision. Visual windows must be specified in terms of visual angle, rather than in absolute size (unless the distance from the operator to the window is also specified). The further away from the observer the window is placed, the larger in size it must be to maintain the same visual angle.

A major problem is encountered in translating the primary requirement of seeing a particular visual feature into a visual window specification. The problem is that different sized and positioned visual windows would be required to see the same visual feature from differently configured equipment. Thus, if visual windows were used to specify requirements, a different set of windows would have to be specified for each configuration of equipment.

The second approach to specifying visual requirements eliminates this problem by eliminating the need to translate visual features into visual angles. The approach specifies the requirements in terms of specific locations or visual attention locations which must be visible from the operator's position. The key to the approach is to specify the locations with reference to machine points. In this way, the requirement will apply to all configurations of the equipment class. For example, operators may be required to see an object on the ground a necessary stopping distance ahead of the machine. This point can be located in space as follows:

Fore-Aft:	Front edge of machine + necessary stopping distance
Lateral:	Machine center line
Vertical:	Floor

The requirement, as written, does not change if the length of the equipment changes, the operator's posture or position changes, or if the width or height of the machine changes. Thus, the requirements are generalizable to all equipment with a given class, i.e., all continuous miners, all shuttle cars, etc.

It was the above considerations that led to the adoption of the second method for specifying visual requirements in this study. For each class of equipment a separate list of requirements was generated. In all cases the requirements identify a visual attention location in space (fore-aft, lateral, and vertical) in which one or more important visual features were located. One goal was to maximize the number of visual features accounted for by using a minimum number of visual attention locations.

The complete list of visual attention locations for continuous miners, shuttle cars, and scoops is contained in Sanders (1981). For illustrative purposes, we have provided Figure 1, a top view of a continuous miner, showing

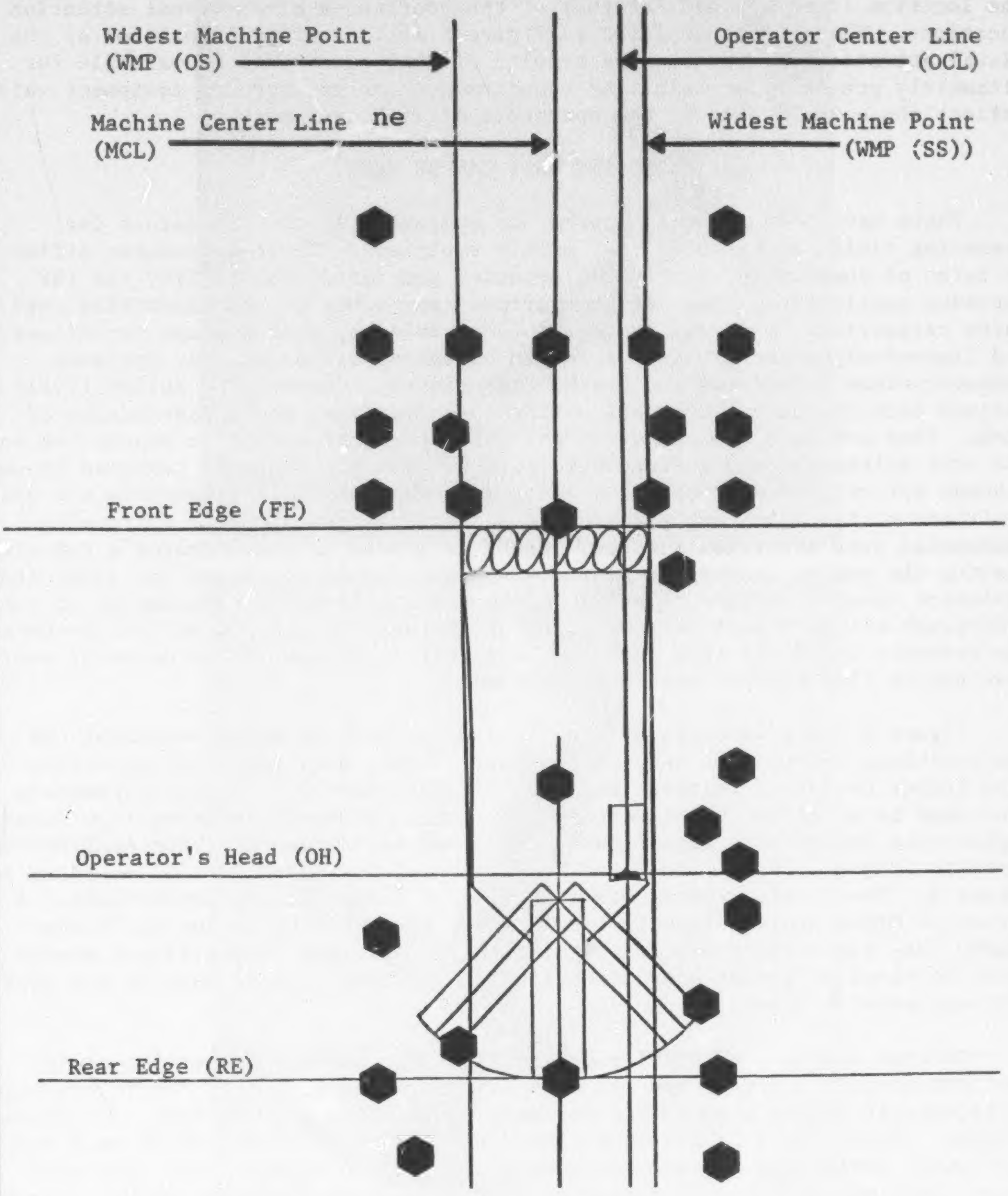
Widest Machine Point
(WMP (OS)
Operator Center Line
(OCL)
Machine Center Line
ne
(MCL)
Widest Machine Point
(WMP (SS))
Front Edge (FE)
Operator's Head (OH)
Rear Edge (RE)

FIGURE 1. - Visual attention locations (fore-aft and lateral) for continuous miner operation.

the location (fore-aft and lateral) of the continuous miner visual attention locations. What is not depicted in Figure 1 is the vertical position of the visual attention locations. The results of this study will be valuable for ultimately prescribing visibility requirements for underground equipment which reflect the actual needs of the operators of such equipment.

ASSESSING WHAT CAN BE SEEN

There have been numerous approaches suggested in the literature for assessing fields of visibility of mobile equipment. These approaches differ in terms of complexity, type of information generated, and utility for the intended application. Most of the various approaches can be classified into three categories: panorama photographic techniques, shadow graph techniques, and line-of-sight techniques. A fourth category, miscellaneous, includes computer-aided procedures and graphic techniques. Sanders and Kelley (1981) discuss each of these approaches noting the advantages and disadvantages of each. They conclude that an outside-in line-of-sight technique appears to be the best suited for the current application. The procedure is centered around a human eye reference measurement instrument (HERMI) which represents the eye positions of the 5th percentile female and 95th percentile male performing reasonable neck and trunk flexion. HERMI is placed in the operator's cab simulating the position of the operator. At each visual attention location, the evaluator takes a picture of HERMI in the operator's cab. Examination of the photograph allows direct determination of whether the 5th and/or 95th percentile operator could see that location, and whether to see it the operator would have had to flex his/her neck and/or trunk.

Figure 2 shows pictures of HERMI. The two arcs on HERMI represent the eye positions for the 5th percentile female (lower arc) and 95th percentile male (upper arc) in a relaxed (slumped) sitting posture. The anthropometric data used to construct HERMI represent military personnel as taken from Human Engineering Design Data Digest (HEL, 1978) and Anthropometric Data Application mannikin (Rogers, 1976). Neck and torso flexion was taken as ±35° as shown in Figure 3. The ± value represents mean flexion from military populations. A Bureau of Mines project (Contract H01387022, Biomechanics In Low Coal) concluded that coal miners are not significantly different from military populations in terms of linear body dimensions, hence HERMI can be used in the coal mine equipment context.

Several features of HERMI make it unique for underground mining equipment application. First, the eye arcs are hinged so that they can be oriented perpendicular to the ground from any seat back angle, from upright to full reclining. People in a partially reclined position will rotate their neck forward until their eyes are facing forward. HERMI can imitate this maneuver. Second, the eye arcs can be retracted toward the center line of HERMI. In the event an obstruction exists in a cab which would prevent torso flexion to the full 35° to one side or the other, the eye arc can be shortened to represent the restricted space. Third, HERMI is constructed with stand-offs to maintain

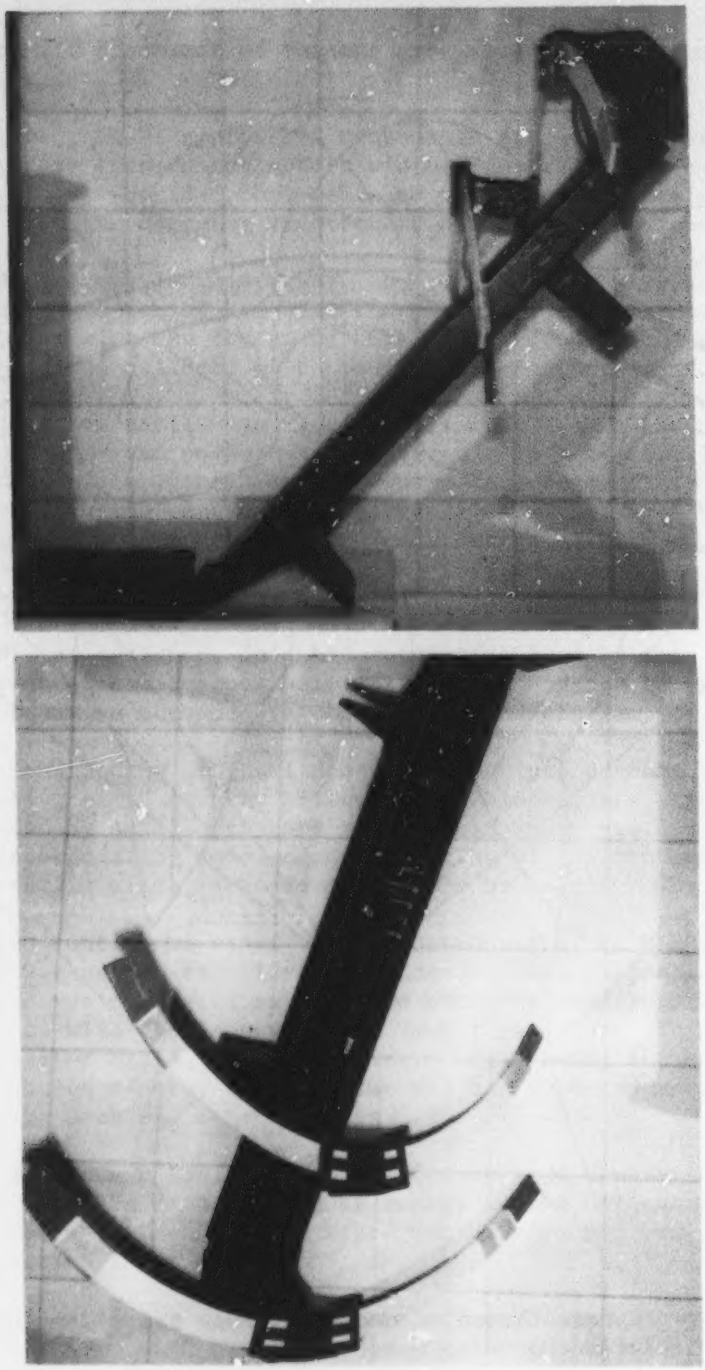

FIGURE 2. - HERMI

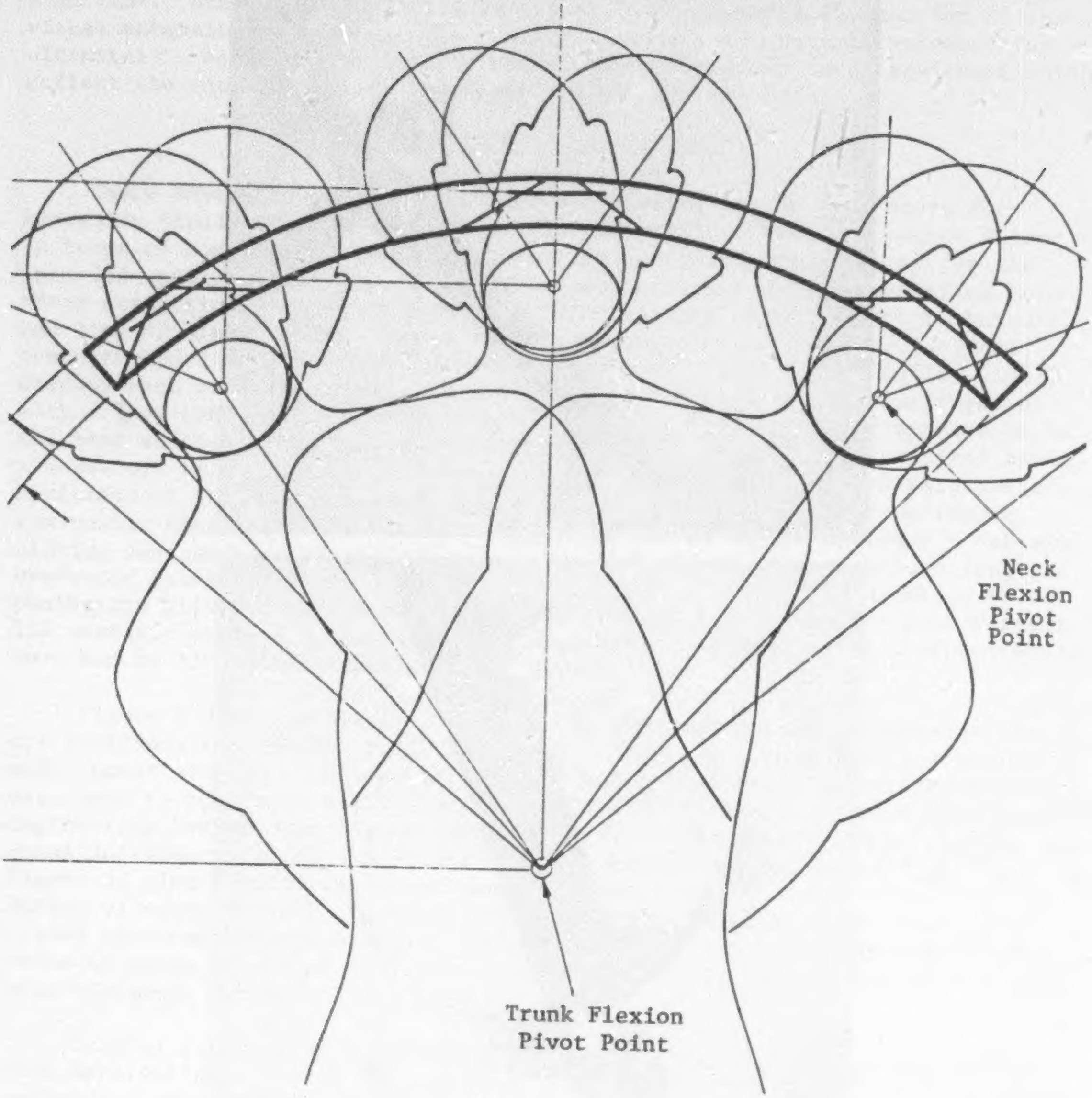
Neck
Flexion
Pivot
Point
Trunk Flexion
Pivot Point

FIGURE 3. - Representation of neck and trunk flexion and resulting eye arc used to construct HERMI.

the proper fore-aft placement of the eye arcs when the operator leans back against the seat.

As configured, HERMI represents reasonable operator postures. An actual operator might lean forward to improve visibility or flex more than 35° from side to side. It was decided that vehicles should not be designed to require such movement from the operator in order to see important visual features.

HERMI, as designed in this study, however, must be viewed as a first generation eye reference measurement instrument. During this project, the following limitations with the design of HERMI were noted which should be corrected to improve the validity of the information gathered:

1. The 5th percentile eye ring assumes that such a person would assume the same posture as a 95th male in the cab. Thus, in a low canopy cab, the 95th male would have to move his buttocks forward in the seat. A 5th percentile female, on the other hand, could sit more erect. The current design of HERMI does not permit this. The next generation HERMI will be designed to incorporate such independent posturing.

2. HERMI, as designed, does not automatically take into account clearance requirements between the eyes and the top of the canopy necessary to accommodate the hardhat and cap lamp of the miner.

3. The positioning of HERMI does not take into account the use of "seating aids" such as pillows, wood blocks, etc., which could be used by small operators to increase their seating height. By incorporating independent posturing of the 5th and 95th percentile rings, seating aids could be used.

A drum head continuous miner was evaluated using the HERMI methodology and the visual attention areas identified during this project. The drum head continuous miner was evaluated twice, once with the canopy in the highest position and once with the canopy in the lowest position. This particular machine was selected based on availability. While being representative of drum head continuous miners, this machine was not selected because of any unique visibility problems or attributes.

Figure 4 presents a few examples of side-by-side comparison of HERMI pictures taken with the drum head miner canopy in the highest and lowest positions. The numbers in the upper right corner of each picture correspond to the visual attention locations.

Figure 4 dramatically illustrates the effect of raising or lowering the canopy on visibility. With the canopy in the lowest position, vision is severely restricted. The situation is considerably better with the canopy raised. This is especially obvious in pictures 23, 25, and 26.

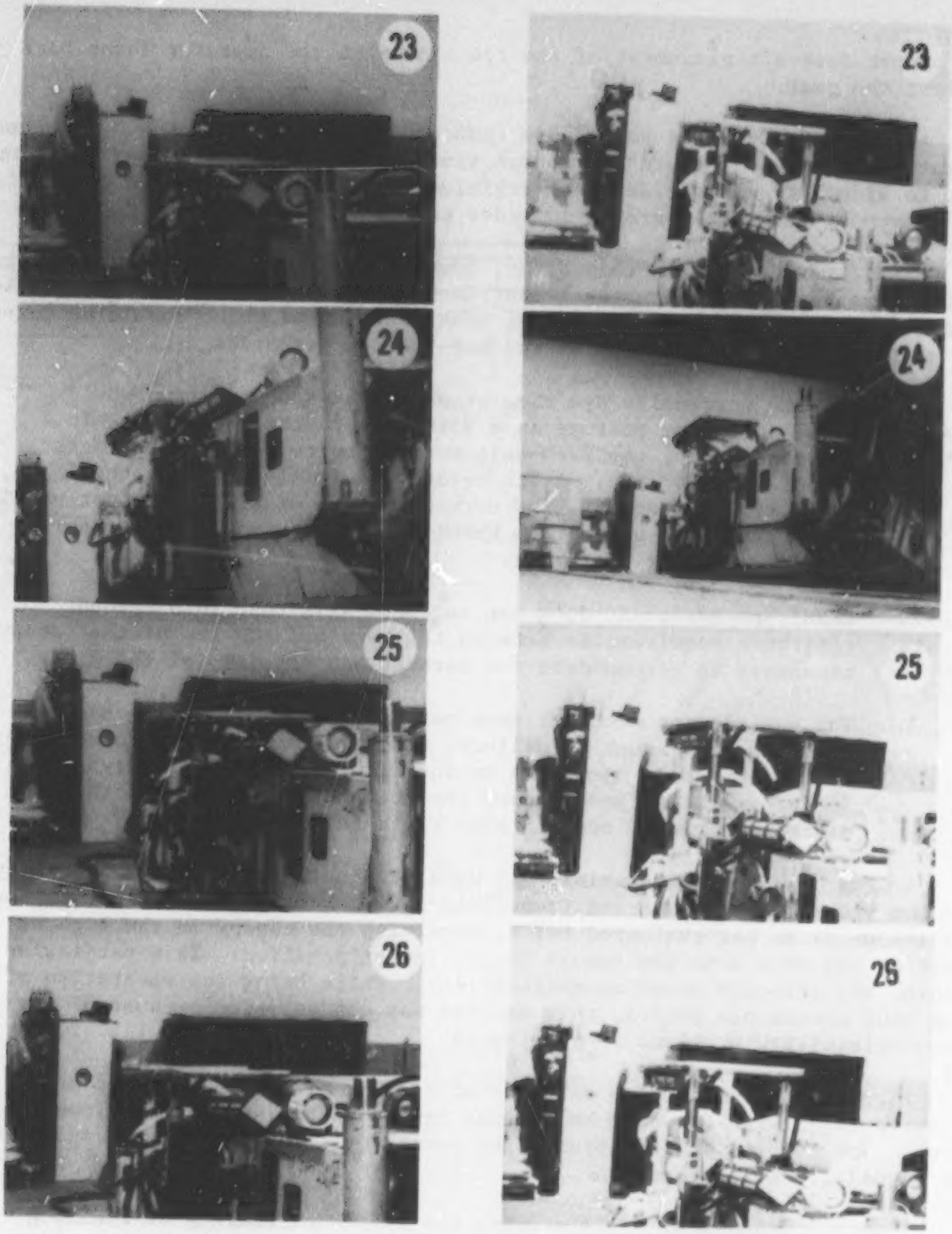
23
23
24
24
25
25
26
26

FIGURE 4. - Visibility comparison of a continuous miner with canopy in highest and lowest positions.

Several design features of this particular machine result in restricted visibility. The position of the fluorescent lights on the side and in front of the operator's cab is one example. The light on the side of the cab prevents the 95th percentile operator from flexing his torso to see. This is shown vividly in picture 25 high. The light in front of the cab obstructs vision in the low canopy condition for the small operator as shown in pictures 23 and 26 low.

Another example of design obstructions is the placement of the canopy supports and hoses. Pictures 23 high and 25 low and high show how the canopy post and hose obstructs vision in the center of HERMI'S eye arcs, thus requiring an operator to flex his torso to see the visual attention location.

The HERMI technique, in conjunction with visual attention locations, is a powerful technique for evaluating the visibility afforded the operator by the specific design of the equipment. Obstructions are clearly identified, and the consequences of redesign are readily apparent.

TITLE OF PAPER: Disability Glare Studies on
Underground Mine Personnel

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Mr. Crouch received a B.S. Degree in Electrical Engineering from the University of Michigan, and is a Registered Professional Engineer in the state of New York. His professional career included service with Holophane Company, involved in engineering design and application work; with Wipperman Mitchell, Inc., as an illuminating engineer; and with Buffalo-Niagara Corp. as industrial lighting and special application engineer.

In 1944, Mr. Crouch became Technical Director of the Illuminating Engineering Society, and Secretary-Technical Advisor to the Illuminating Engineering Research Institute. As Technical Director, Mr. Crouch conceived and helped produce the first IES Lighting Handbook. He also initiated, planned, and coordinated projects in the fields of street/roadway lighting and school lighting, and participated in the development of standards and recommendations for various types of specialized lighting applications.

In 1967, Mr. Crouch became Director of Research and Secretary/Treasurer of the Illuminating Engineering Research Institute. During this period he developed comprehensive research programs covering:

- basic research in the visual process and the relationship of light to visual performance
- development of characteristics of the optimum visual or luminous environment
- studies of the luminous environment to apply to typical conditions found in commerce and industry

In 1941, Mr. Crouch was the recipient of the Niagara Award; and in 1968, the IES Gold Medal. Mr. Crouch is an international lecturer in the field of light and vision as related to illuminating engineering; and is the author of numerous technical papers resulting from original research in the field of illumination engineering.

Mr. Crouch is affiliated with the following professional organizations:

Member of Illuminating Engineering Society (IES) since 1930 and Fellow since 1946

Fellow of the American Association for the Advancement of Science

Member of Optical Society of America

Affiliate Member, Institute of Traffic Engineers

Member, U.S. National Committee of the International Commission on Illumination
Member, Council of Educational Facility Planners, International Illuminating Engineer for 51 years

Member, American Society of Photobiology

DISABILITY GLARE STUDIES ON UNDERGROUND MINE PERSONNEL

by

C. L. Crouch[1]

ABSTRACT

A recent survey of miners operating both under high seam and low seam conditions indicated problems with current types of mine lighting. Seventy-eight percent of the miners interviewed had complaints or questions regarding the lighting systems from the viewpoint of discomfort glare, disability glare, veiling reflections, and after-images. These complaints resulted in the question as to whether the underground mining population was more sensitive to glare than the aboveground population in commerce and industry. If they were more sensitive, then the glare formulas should be changed so that improved lighting designs could be made for mine illumination. The U.S. Bureau of Mines sponsored a study by the Bituminous Coal Research, Inc., and a joint study was carried out by BCR and IERI. A large number of observers were tested for disability glare and the results of this study are being presented in this paper.

INTRODUCTION

In recent years the system of lighting of mines has changed from only caplamps to both caplamps and general lighting with the luminaires mounted on the machines. In general these luminaires consist of diffusing-type equipment both incandescent and fluorescent. The fluorescent luminaires consist of fluorescent lamps enclosed in a cylindrical diffusing housing. This introduction of general lighting luminaires has greatly changed the visual environment, and in general has received favorable reaction of the miners even though there are a number of complaints. A survey of their reaction has indicated in general that they would not want to revert to the former system of caplights only. Seventy-eight percent of the miners interviewed had complaints or questions regarding the lighting systems from the viewpoint of discomfort glare, disability glare, veiling reflections, and after-images. These complaints resulted in a serious concern on the part of the Mine Safety and Health Administration of the U.S. Government and the U.S. Bureau of Mines. The Bureau of Mines wished to correct the situation and instituted a study of both discomfort glare and disability glare, first from current lighting systems, and second, the sensitivity of miners to the two forms of glare.

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The Bituminous Coal Research, Inc., and the Illuminating Engineering Research Institute have collaborated in making a study of these two phases.
Dr. Sylvester Guth is reporting at this session on the discomfort glare phase, and this paper is concerned with the disability glare portion.

DISABILITY GLARE

In 1925, Holladay (1) discovered that disability glare reduced the visibility of objects or tasks to be seen. He found that for glaring lighting units, the glare effect could be represented by an equivalent uniform luminance overlaying the object to be seen. In 1928, Stiles (2) of England confirmed the Holladay concept and published a paper in the International Commission on Illumination (CIE) proceedings. In 1935 he confirmed the formula that Holladay had developed. In 1955 Fry (3) further confirmed the concept. Still later, Blackwell (4) developed the modification that the equivalent uniform luminance of the glare sources both caused an increase of adaptation, thus sensitivity, as well as a loss. The net result, in general, was a loss. He developed formulation that would take into account both effects. This formula as given in the CIE Report 19/2, Vol. I, is as follows:

$$\mathrm{DGF} = \frac{L \times \mathrm{RCS\ for}\ L_e}{L_e \times \mathrm{RCS\ for}\ L}$$

where L is the luminance of the background of the task without glare and $L_e = \frac{L + L_v}{1 + aK}$. K represents the scatter effect of the rays of light in the eye media and "a" is the portion of the visual field occupied by the glare sources. "a" is a proportionally constant determined by the angular dimension of the surround. L_v is the equivalent veiling luminance from the glare sources. RCS is the relative contrast sensitivity. DGF = the disability glare factor.

PHYSIOLOGICAL BASIS OF DISABILITY GLARE

Fry (5) and other researchers found that there was a scatter of the light from the glare sources through the eye media involving the cornea, the lens, the vitreous humor, and the retina itself. This scattering of light caused an internal veiling luminance to be superimposed upon the focused image that the observer was trying to see.

EFFECT OF AGE

Fisher and Christie (6) in 1965 found that there was a definite age factor involved in disability glare. Their studies were related to roadway lighting. In 1973 and 1974, Italian investigators led by Lucia Ronchi (7) determined that the disability glare factor was dependent upon pupil size, and therefore the K factor in the above formula changed to a higher value at low levels of illumination involved in roadway and mine lighting as compared with the higher levels used in interior lighting.

Blackwell (8) made very comprehensive tests on various age groups and with high and low levels of illumination and determined the K factors involved. Further he was able to determine the change of the K factor for age. For 100 candelas per square meter, $K = 10\ m_3$. For 1.7 candelas per square meter, $K = 10\ m_4$. "m_3" and "m_4" are as follows:

m_3

Age 20 - 44 years $m_3 = 1.000$
44 - 64 $= 1.000 + .0310(A - 44)$
64 - 80 $= 1.620 + .0725(A - 64)$

m_4

Age 20 - 44 years $m_4 = 1.500$
44 - 64 $= 1.500 + .0419(A - 44)$
64 - 80 $= 2.338 + .0668(A - 64)$

INSTRUMENTATION

Fry (9) in 1955 presented a proposed lens for mounting on the front of a luminance meter that would proportion the response of the photocell through the optical system in accordance with the disability glare effect. This concept was further developed in an actual glare lens in 1963 (10). This has been used considerably in street lighting in this country. In 1959, Blackwell (11) developed a Visual Task Evaluator (VTE) for measurement of visibility of tasks in commerce and industry. This consisted of a contrast threshold meter that would reduce the unknown task to threshold and then by calibration determine an equivalency between that task and a laboratory test object on which visibility data had been extensively recorded. Later models were modified and the current model includes a limited exposure time of 200 milliseconds to the observer. The field of view of this instrument is limited to a range of two to three degrees. This therefore records the foveal response to the visibility of the object. More recently, in order to determine the factor of age he was able to introduce into the optical train of the VTE an enlarged field of view of 27 degrees subtense. Due to the fact that there is a change with pupillary opening and therefore with the level of illumination and with age and the variability between observers, the Visual Task Evaluator has now been altered to allow an attachment of a disability glare evaluator which inserts in the optical train the field of view of 27 degrees. Thus the VTE with the attachment can evaluate the visibility of the task without glare and with glare. This instrumentation has provided a means of evaluating the sensitivity of miners under the low level illumination found in the current lighting of mines.

EVALUATION OF DISABILITY GLARE FROM CURRENT LIGHTING SYSTEMS

The first phase of the study was to determine from current formulae whether current lighting systems being used in mines caused disability glare. Seven different systems were put on a continuous miner and later on a bolter in a simulated mine environment representing a nominal 0.06 fL wall luminance (0.206 candelas per square meter). Several positions were taken around each machine for the purpose of making measurements. These positions were pointed out by company engineers in charge of the installation of the lighting systems. These positions represented critical visual locations where the miners would be involved in working around the machines. The results of measurements are shown in Tables 1 and 2. You will note a great variation in resulting visibility since disability glare factor (DGF) means the percentage of visibility still left after the glare effect. These measurements of course made use of the current formulation as developed by Blackwell and described above.

EVALUATION OF DISABILITY GLARE SENSITIVITY OF MINERS

The Visual Task Evaluator with its disability glare attachment was set up at the Maple Meadow Mine outside of Beckley, West Virginia, and further at the Derby and Prescott mines near Big Stone Gap, Virginia. The test set-up was shielded by black curtains, and the general environment was maintained between 0.06 and 0.07 fL (0.206 & 0.240 candelas per square meter). Part of the time a second VTE was operating in another location where a higher level was provided between 6.75 and 7.31 fL (23.1 & 25.0 candelas per square meter). (Later the VTE being used for the higher level failed and the measurements were continued under the low level.) 110 observers were involved in the three locations. A number of the 110 observers were not only tested once but also came in for a retest. A portion of the tests concerned not only the low level luminance but also the higher luminance as well.

Dr. Blackwell had tested 235 observers in the laboratory for disability glare at 1.7 & 100 cd/m^2 (0.49 & 20 fL). To determine the age effect in disability glare the 235 observers were divided into 5 decades of age. Further, Dr. Blackwell had access to the studies of Prof. Dr. Werner Adrian[2] which made an overall figure of approximately 400 observers tested in two laboratories for disability glare. From these combined data Dr. Blackwell was able to predict what would occur if the two sets of observers had participated under the same conditions that the miners had tested. Taking the average of all these predictions this population would have a predicted disability glare factor, DGF, equal to 0.582 which includes the effect of age. This DGF value accounts for a 41.8 percent loss in visibility. Upon analysis of the 110 miners Dr. Blackwell found the disability glare factor, DGF equal to 0.598 which accounts for a 40.2 percent loss in visibility.

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[2] University of Karlsruhe, Germany.

TABLE 1. - DGF measurements for the continuous miner

Lighting system	Position 1	Position 2	Position 3	Position 4
A. 15w fluorescent	(T1) **	(T10) 1.000	(T23) 0.043	(T24) 0.791
B. 1500 ma........ fluorescent	(T2) 0.018	(T14) 0.644	(T28) 0.806	(T29) 0.578
C. 1500 ma........ fluorescent	(T3) 0.193	(T12) 0.291	(T26a)0.670	(T25) 0.617
D. 1500 ma........ fluorescent	(T4) 0.473	(T11) 0.815	(T15) 0.241	(T16) 0.552
E. 1500 ma........ fluorescent	(T5) 0.557	(T13) 0.477	(T26b)0.487	(T27) 0.574
F. Incandescent... (Unshielded)	(T6) **	(T9) **	xxx	(T17) 0.317
G. Incandescent... (Shielded)	xxx	xxx	(T19) 0.645	(T18) 0.492
H. Incandescent... (Unshielded)	(T7) 0.677	(T8) **	xxx	xxx
I. Incandescent... (Partial shield at 45 degrees)	xxx	xxx	(T22) 0.104	xxx
J. Incandescent... (Shielded)	xxx	xxx	(T20) 0.977	(T21) 0.311

TABLE 2. - DGF measurements for the Acme bolter

Lighting System	Position 1	Position 2	Position 3
A. 1500w fluorescent...........	(T1) 0.116	(T6) 0.229	(T11) 0.100
B. 1500 ma fluorescent.........	(T2) **	(T7) 0.071	(T12) 0.100
C. 1500 ma fluorescent.........	(T3) 0.411	(T8) 0.360	(T13) 0.306
D. Incandescent................	(T4) 0.637	(T9) 0.573	(T14) 0.039
E. Incandescent................ (Shielded)	(T5a)0.679	(T10b).025	(T15) 0.358
F. Incandescent................ (Unshielded)	(T5b)0.395	(T10a).400	

xxx - Position was not measured
** - DGF could be calculated

From the analysis of the writer and Dr. Blackwell comes the conclusion that as far as disability glare is concerned, the miners were in agreement with the studies of Blackwell and Adrian which had been conducted under more carefully controlled laboratory conditions. There had been very large variations among the mining observers in response to disability glare as measured under field conditions.

SIGNIFICANCE OF THE DISABILITY GLARE EVALUATIONS

It would appear from the analysis to date (the analysis is still continuing) that one can expect roughly a 40 percent loss or more in visibility (see tables 1 & 2). If one uses the figure of 40 percent loss of visibility and applied it to interior lighting such as office and commercial lighting, one could expect a visual performance loss between 20 to 25 percent for the tasks in these environments. Probably under mining conditions where the visibility of an object is poor and the illumination level low, the loss of visual performance would be much greater. One would need to have the visibility measurements of actual objects to be seen in mines to carry out a visual performance analysis for the mine environment.

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TITLE OF PAPER: Determination of Safety Lighting Needs for Exterior and Interior Areas of Coal Preparation Plants

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DETERMINATION OF SAFETY LIGHTING NEEDS FOR EXTERIOR AND INTERIOR AREAS OF COAL PREPARATION PLANTS

by

Richard L. Vincent[1]

ABSTRACT

A study was conducted to determine what levels of light are required for safe working conditions to be maintained in and around coal preparation plants. Visual Task Evaluator measurements were made at three preparation plants at Beckley, West Virginia. Fifty-one tasks were selected and measured from which levels of light required by both young and older miners were determined.

INTRODUCTION

Proposed regulations for the illumination of coal preparation(1) plants' interior and exterior areas were discussed in a March 1977 meeting(2) of the Illuminating Engineering Society of North America, IESNA, Committee on Mine Lighting. During the Committee meeting it was emphasized that illumination levels required for safety of workers should be obtained.

A study to find the safety levels of illumination was sponsored by Bituminous Coal Research, Inc., Pittsburgh, Pennsylvania. The field testing and analysis were conducted by the Illuminating Engineering Research Institute of New York City with the supervision of Mr. C. L. Crouch, the IERI Director of Research and the author serving as the investigator.

The IESNA Committee selected three coal processing plants in Beckley, West Virginia for the study. Of the plants, one was old, one new, and the third had new yard lighting. The study took place in May 1977. The Visual Task Evaluator, VTE, was used to measure the visibility of 51 selected visual tasks (see figures in Appendix). In order to keep a constant light level during the visibility measurements, most tasks were measured at night or where daylight was minimized. The geometric distribution of light produced by each plant's lighting system was utilized in the visibility measurements. Illumination requirements were then determined for each task based on the visibility of the critical details to be seen (see Tables 1A-1B). Reflectance values for each task were obtained based on the Munsell System.

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VISUAL TASK EVALUATOR

The Visual Task Evaluator, VTE,(3) is a contrast threshold meter developed to assess the visibility of unknown details in the real working world. An operator of the VTE looks through the instrument at a detail of concern and adjusts an internal veiling luminance which is superimposed over the detail. As the veiling luminance is increased, the contrast of the detail is reduced. The operator adjusts the veiling luminance until the detail can just barely be seen. The point of bare seeability is called the threshold for the detail being measured. At threshold, all objects become equal in visibility; therefore, they can be compared to find what factor would make them equally visible above threshold. This comparison is important because it allows unknown details in the field to be compared with known details which have been studied in the laboratory. Tests have been conducted on college students with normal vision to determine threshold data on a standardized test object, a 4-minute disc (whose diameter subtends 4 minutes of arc at the eye). The relation of how the threshold contrast for the 4-minute disc varies with given light levels is an established function (see Figure A) and is part of the CIE Report 19/2 which relates visual performance to light level(4). The operator of the VTE has previously run through a calibration procedure, based on the 4-minute disc, which produces a calibration curve. The measurement made with the VTE can then be related through the calibration curve to the laboratory threshold data. An Equivalent Contrast, C, necessary to make the 4-minute disc equal in visibility to the unknown detail can then be determined.

DISCUSSION OF FIELD MEASUREMENTS

The VTE was brought to each of the three test sites where knowledgeable personnel described the working operations of the plant and pointed to specific critical visual tasks which needed to be seen for safe and productive work. Critical tasks were selected both in the interior and exterior spaces of the old and new plants. From the interior of the old and new plants critical visual tasks were selected to include: the control rooms, the electrical equipment rooms, workshops, storerooms, walkways, fixed processing equipment, machine wells, elevators, and a bathhouse (see Table 1A). The exterior areas which were surveyed included: active building entrances and exits, storage, coal loading and unloading, conveyor belts, loading platform, walkways, active railroad tracks, track switching points, parking lots, shaft landings, and refueling areas (see Table 1B).

The various tasks were measured using the VTE over a two-night period. In making VTE measurements in some locations of both the old and new plants, the levels of illumination were so low that measurements could not be made through the instrument because of the absorption factor of the VTE optics. Therefore supplementary lighting was placed so that light came from the same general direction as the lighting system would have produced if operating at a higher level of light emission. In some cases, such as the tunnel/conveyor area leading to the exterior depositing area, the supplementary lighting could not be placed to throw light at the same angles that the general lighting

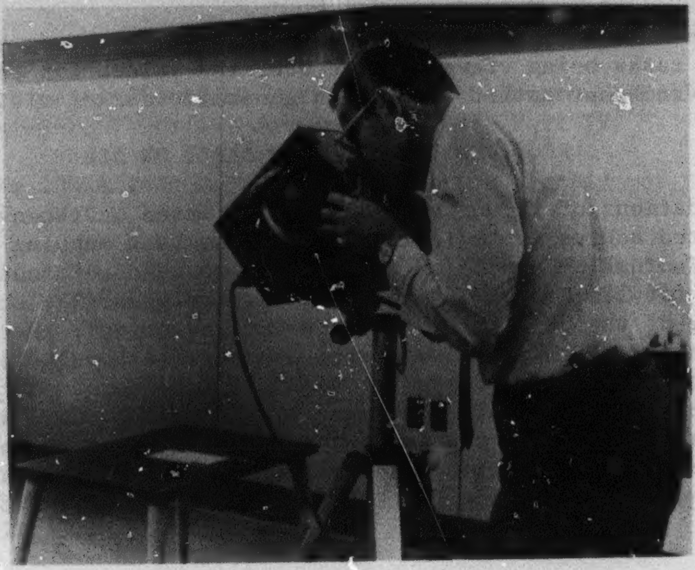

FIGURE A. - The Visual Task Evaluator (VTE) is designed to use 0.2 second exposures that permit more realistic field measurements.

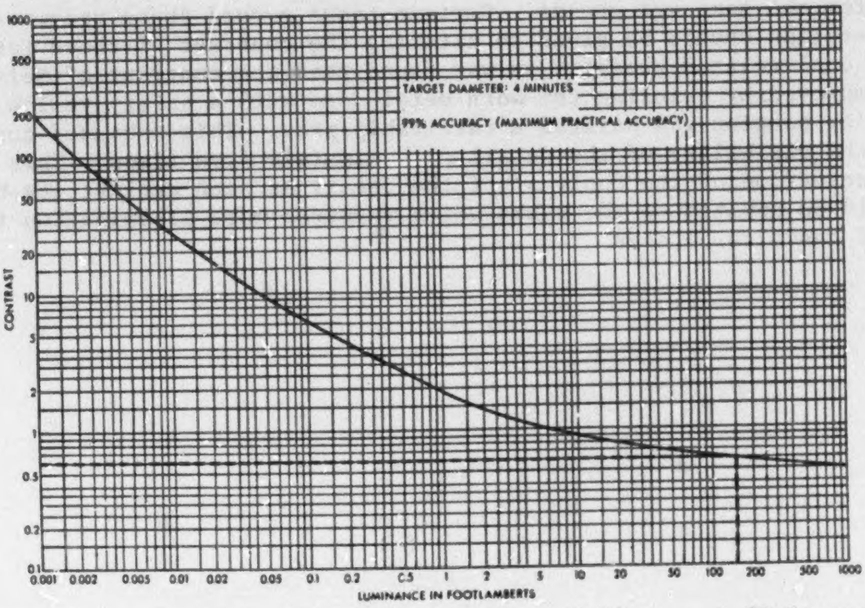

FIGURE A. - Relationship for the standard 4' target (0.2 second exposure time, 99 percent accuracy, and a field factor 8.00) to which practical tasks are equated.

system produced. The distribution and direction of light do alter the visibility of the tasks being viewed; therefore, the values for this area are not altogether correct but rather indicate a general order of visibility.

REQUIRED ILLUMINATION BASED ON AGE

Recommendations of illumination have been based on the average of young, normally sighted adults in their 20's. Work has been ongoing to determine the additional illumination needed as a person ages. The reference, "Visual Performance Data for 156 Normal Observers of Various Ages"(5), shows that for static viewing of the details of the task (not scanning), there is a factor by which the visual performance data of the 20-year old population can be adjusted to account for each decade of age beyond 20 years of age. Through a brief telephone survey by the then IESNA chairman, George Evans, there was an indication that 40-50 years might well represent the average age of the people working in and around the coal preparation plants; therefore, the calculations of illumination required have been made for the 20-30 year decade and the 40-50 year decade.

CONCLUSION AND RECOMMENDATIONS

In reviewing the illumination of the various tasks for the interior spaces of the preparation plants, both old and new, 4-5 footcandles would be required to meet the needs of most visual tasks for the 20-30 year olds and the 40-50 year olds. For the exterior areas, 4-6 footcandles would be required to meet the needs for the same age groups. Certain tasks exceed these recommendations and consideration should be given to altering the contrast of these tasks(6). In another coal-related research it was found that the contrast of metal steps could be improved by painting the worn metal edge with a safety yellow while the remaining portion was painted a battleship gray. This enhanced contrast increased the visibility of the detail approximately five times. This principle of accentuation of the contrast of the detail as seen against its background could be applied to the tasks which required more illumination than the majority of tasks to be seen.

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APPENDIX

TABLE 1A. - Measurements of illumination needs of tasks to be seen in interior spaces of new and old coal preparation plants

Tasks and Location	Munsell index	% Reflectance	Foot-candles 20-30 yr-olds	Foot-candles 40-50 yr-olds
1. Control room & stations				
Old plant				
a) Identification plate....... (white on black)	N2	3.8	0.18	0.25
New plant				
b) Identification plate....... (white on black)	N2	3.8	0.32	0.39
c) Identification plate....... (white on red)	5R 5/12	20.7	2.42	2.90
d) Identification plate....... (see Figure 1(A-D))	5G 6/6	30.0	27.00	76.67
2. Electrical equipment rooms				
Old plant				
a) Position of magnetic....... starter switch	N6.5	36.9	0.05	0.07
New plant				
b) "On" position of switch.... (pressed down)	N7.5	51.4	1.56	2.43
c) Identification plate....... (black on white) (see Figure 2(A-C))	N9	79.7	1.25	1.88
3. Shops				
New plant				
a) Chain on steel plate.......	5YR 5/2	19.7	2.54	3.05
b) Jackhammer and chain.......	N6	30.4	1.05	1.27
c) Tools on the floor......... (see Figure 2(A-C))	N4	12.6	0.11	0.14
4. Storerooms				
Old plant - inactive storage				
a) Port......................	N4.5	16.0	0.16	0.24
New plant - inactive storage				
b) Cylindrical units in aisle	N6.5	36.9	5.42	10.84
c) Port......................	N4	12.6	2.78	3.73
New plant - active storage				
d) Skid...................... (see Figure 4(A-D))	N6.5	36.9	1.90	3.39

TABLE 1A. - (continued)

Tasks and Location	Munsell Index	% Reflectance	Footcandles 20-30 yr-olds	Footcandles 40-50 yr-olds
5. Walkways				
Old plant				
a) Edge of steel grated step	N5	20.4	0.17	0.24
b) Blackened yellow hose	N3	7.1	0.77	1.20
New plant				
c) Large clamp on the floor	N4	12.6	3.25	3.73
d) Piece of coal in wet slick	N2	3.8	0.16	0.22
e) Steel bar resting on stair-rail	N5	20.4	2.30	2.94
f) Wet rubber mat in walkway	N5	20.4	1.57	1.86
g) Steel bar resting on column	N5	20.4	0.74	0.98
h) Pail near column	N5	20.4	1.13	1.42
i) Electric cable on floor (see Figure 5(A-I))	N5	20.4	0.25	0.34
6. Fixed processing equipment				
Old plant				
a) Sluice box on floor (see Figure 6A)	N4.5	16.0	0.30	0.41
7. Machine well				
New plant				
a) Floor flange guard (see Figure 5G)	N5	20.4	0.25	0.34
8. Elevators				
Old plant - man lift				
a) Platform on belt	N4	12.6	0.79	1.19
b) Handhold on lift	N5	20.4	0.20	0.25
c) Entrance platform	N5	20.4	1.57	1.86
New plant - regular elevator				
d) Elevator threshold (see Figure 8(A-D))	N5	20.4	0.49	0.74
9. Bathhouse				
New plant				
a) Doorwedge on floor	N6.5	36.9	3.25	4.74
b) Green hose on bath floor (see Figure 9(A-B))	N5.5	24.9	0.62	0.70
10. Conveyor--belt walkway				
Old plant - unguarded				
a) Roller edge	N4	12.6	0.28	0.37
b) Edge of belt	N4	12.6	0.35	0.40
New plant - unguarded				
c) Roller edge	N7	43.3	0.10	0.13
d) Control wire (see Fig. 10(A-D))	N4	12.6	1.43	1.59

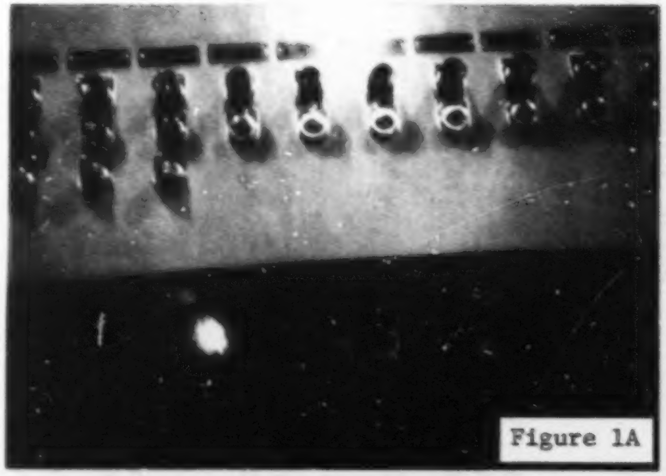


Figure 1A

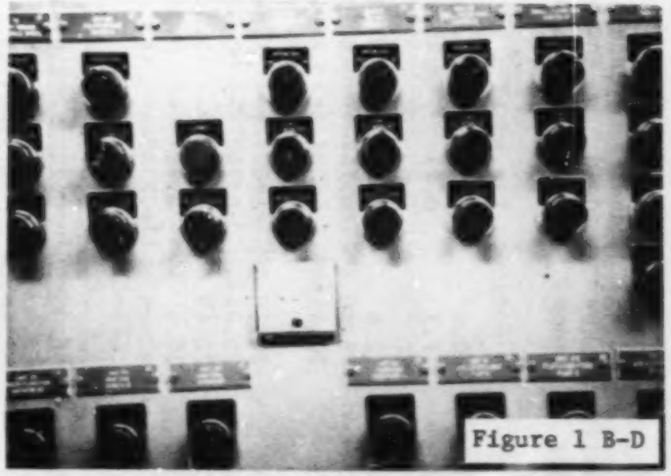
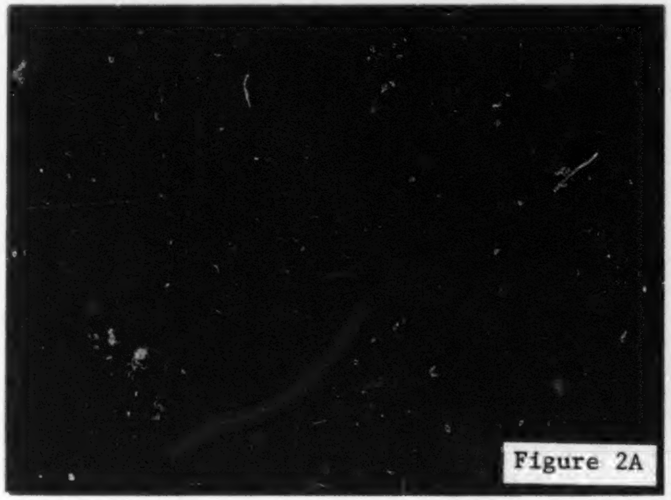


Figure 1 B-D



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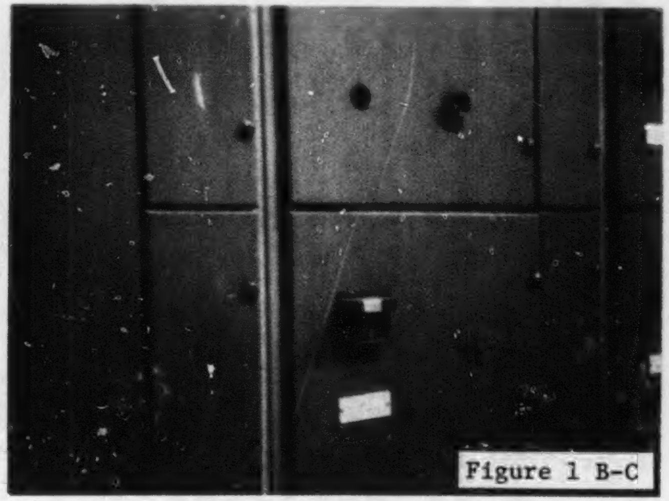
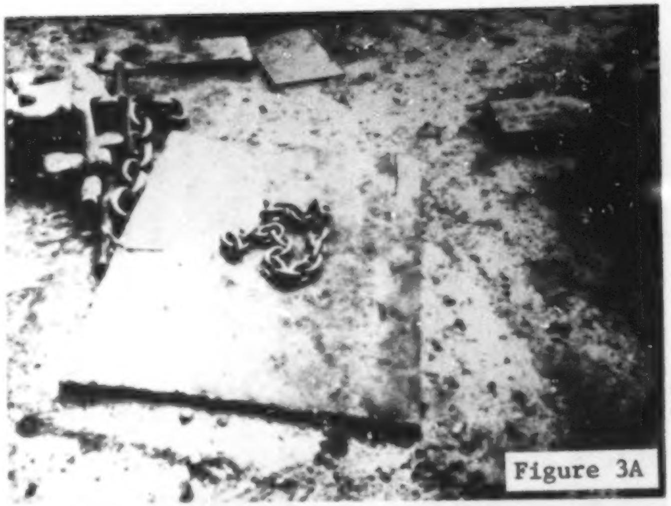


Figure 1 B-C

Table 1A Figures, Page 1 of 8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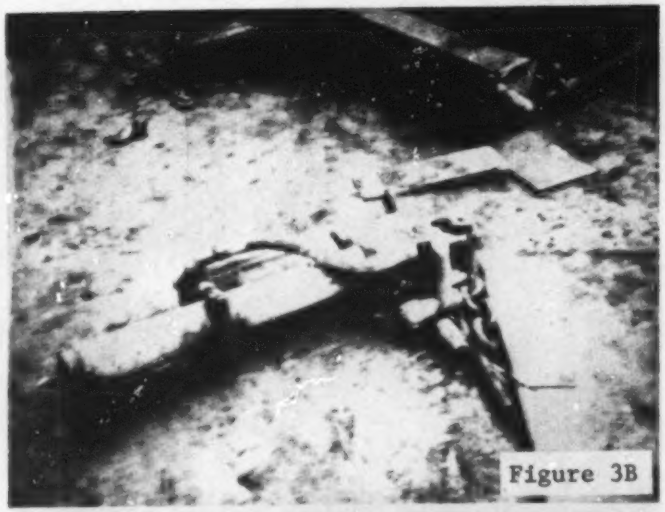
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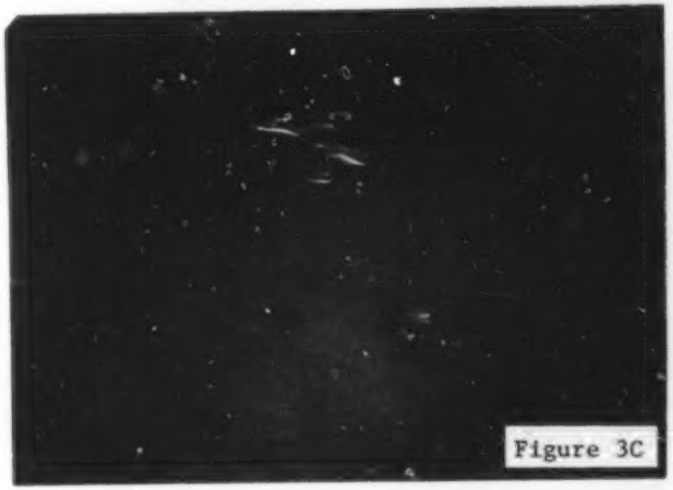


Figure 3C

Figure 4A

Table 1A Figures, Page 2 of 8

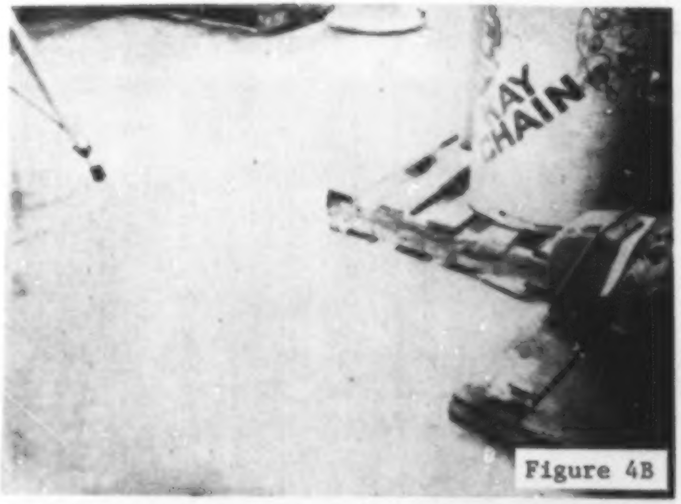


Figure 4B

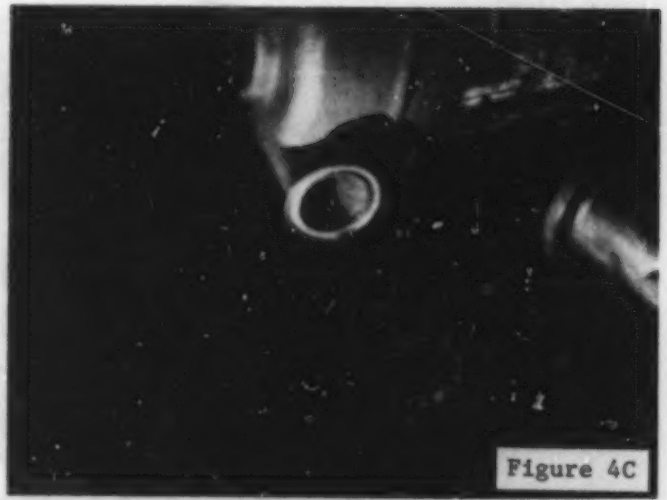


Figure 4C

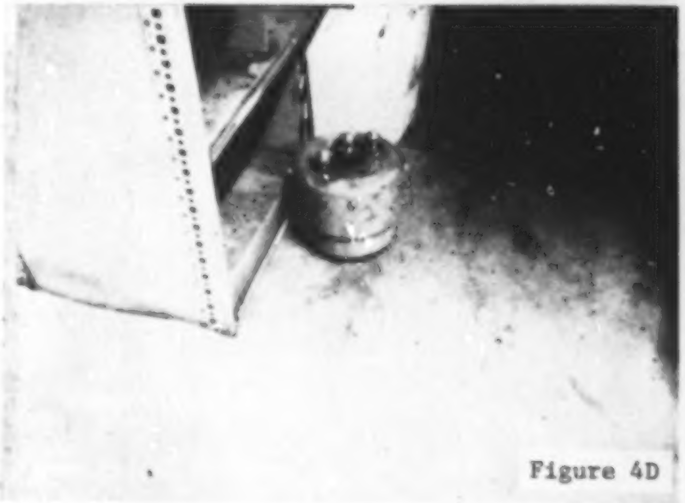


Figure 4D

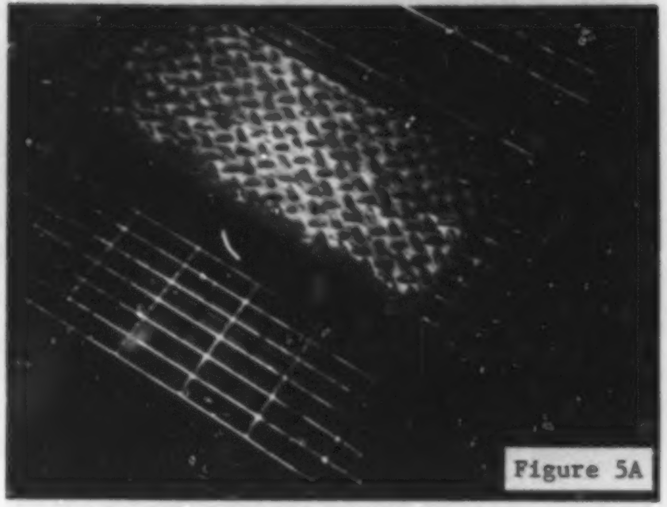
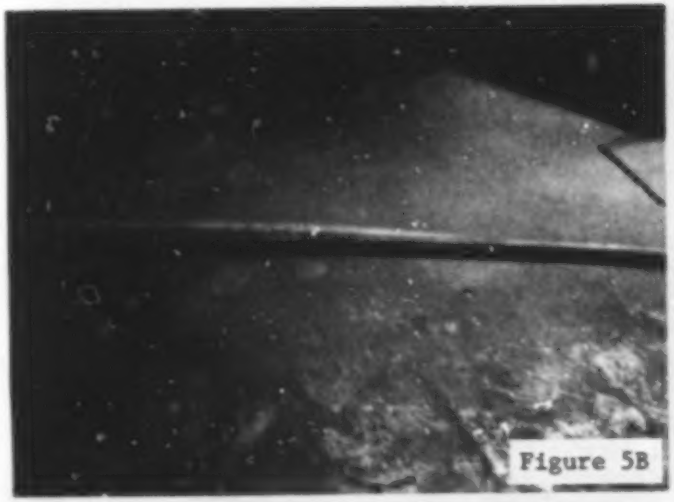


Figure 5A

Table 1A Figures, Page 3 of 8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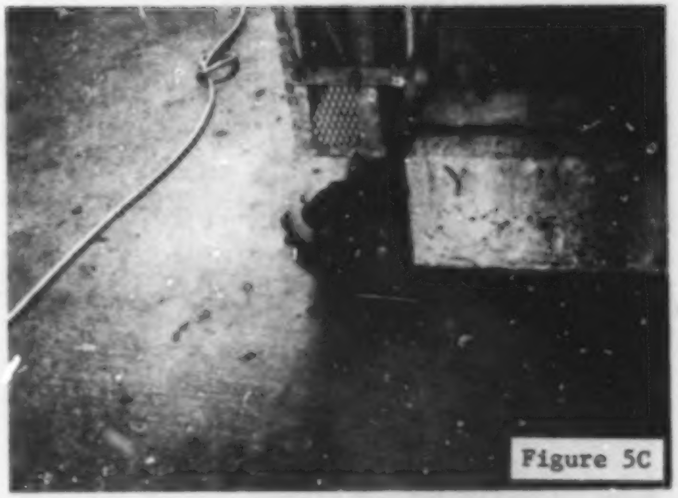


Figure 5C

Figure 5D

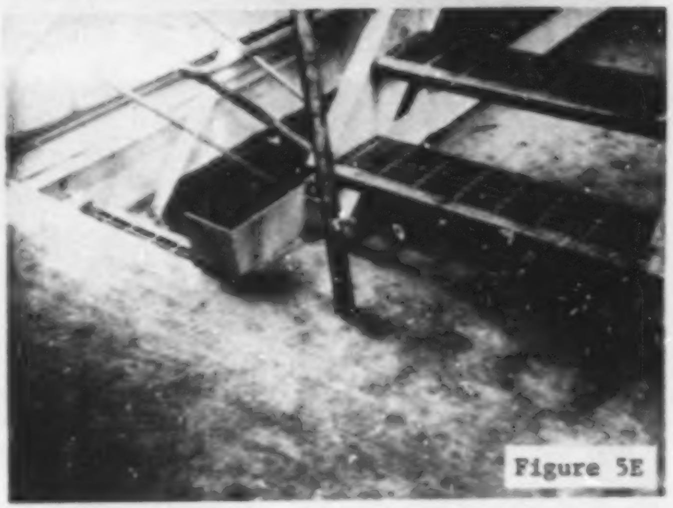
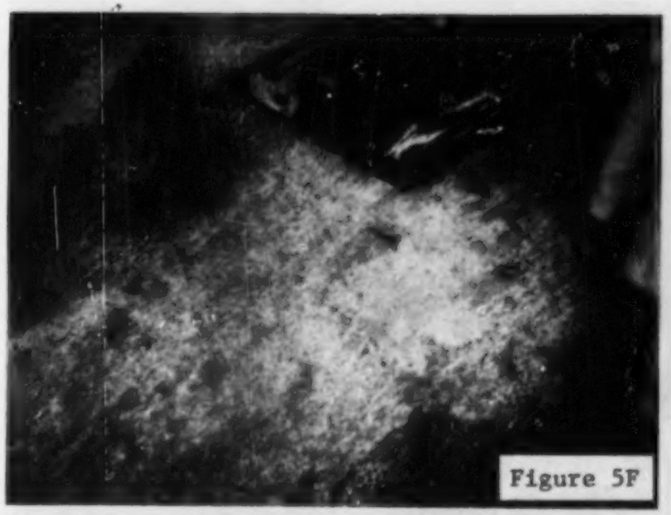


Figure 5E

Table 1A Figures, Page 4 of 8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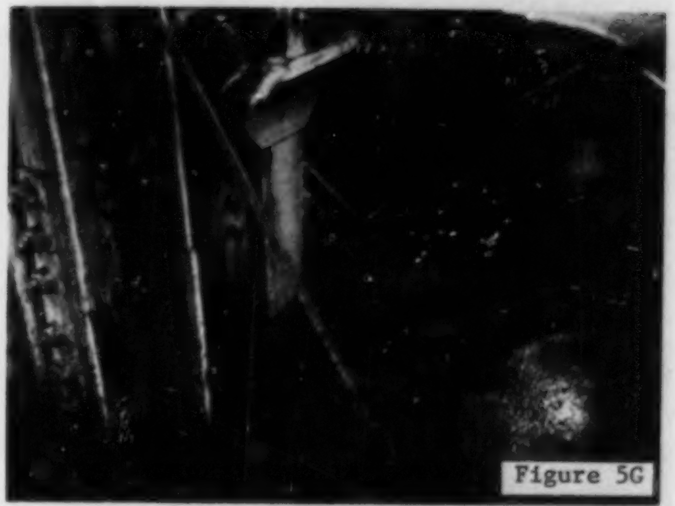
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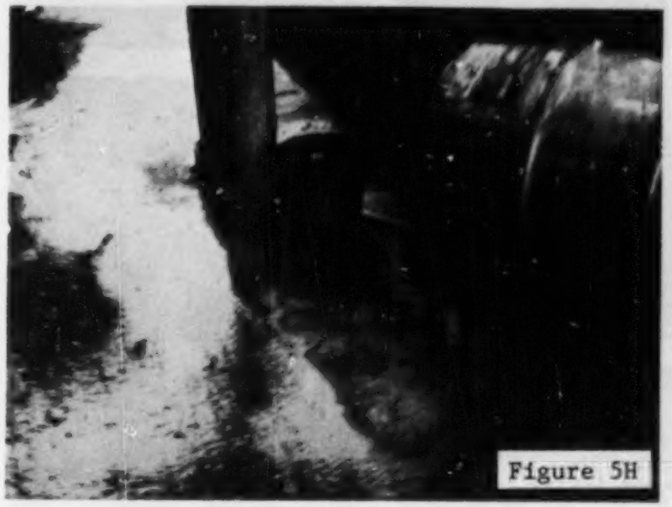
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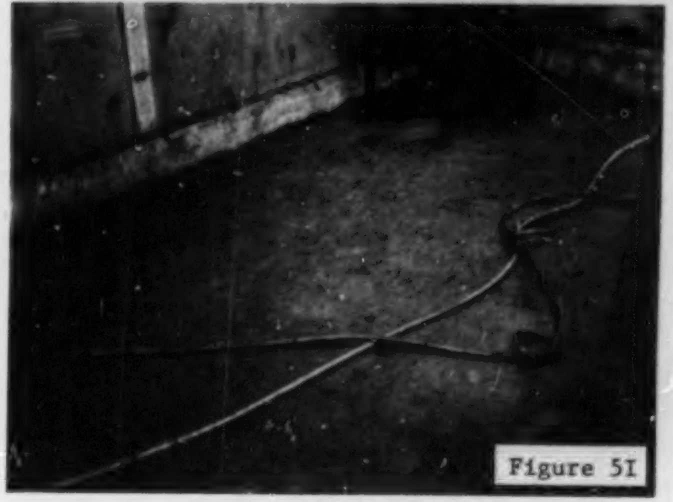


Figure 5I

Table 1A Figures, Page 5 of 8

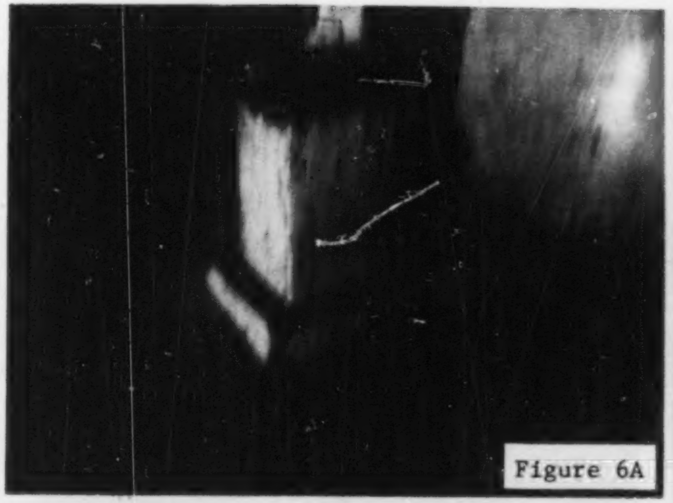


Figure 6A

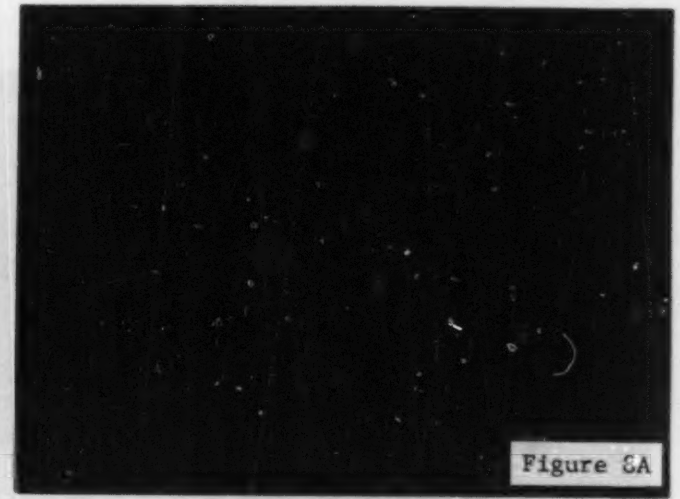
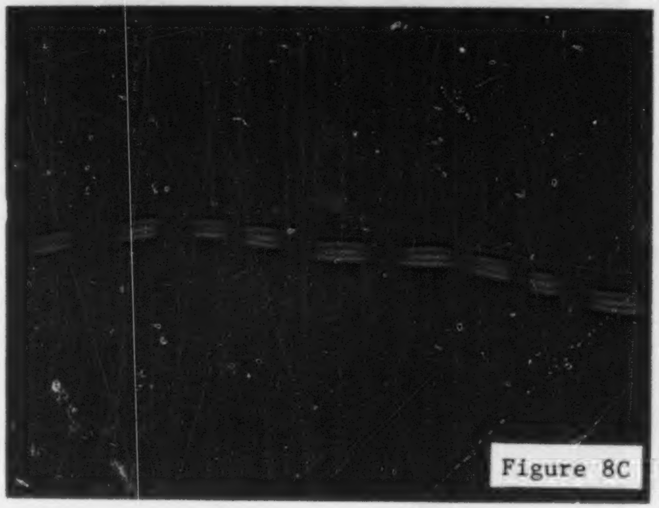


Figure 8A



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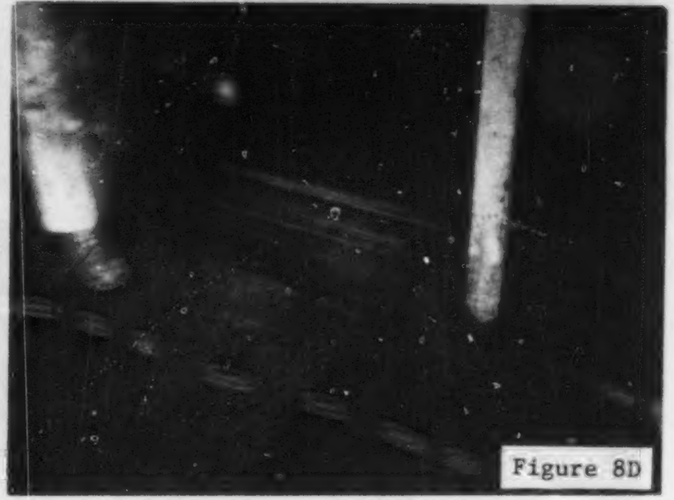

Figure 8D

Table 1A Figures, Page 6 of 8

Figure 9A

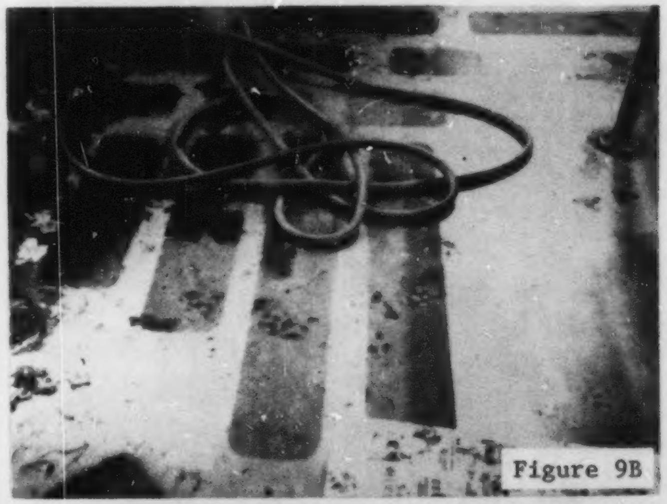

Figure 9B

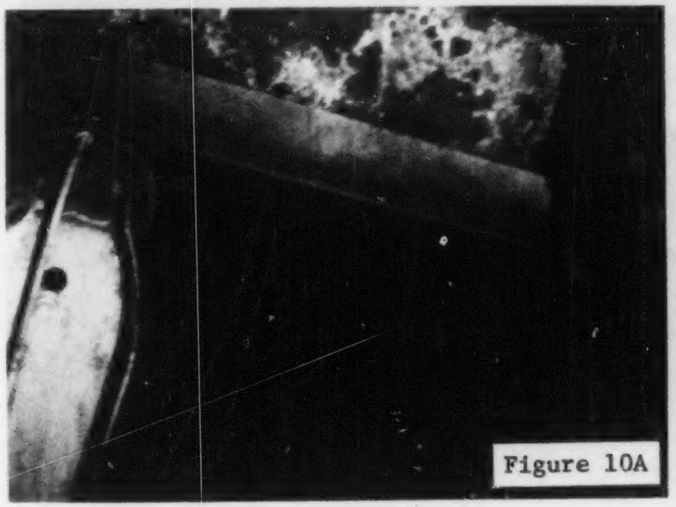

Figure 10A

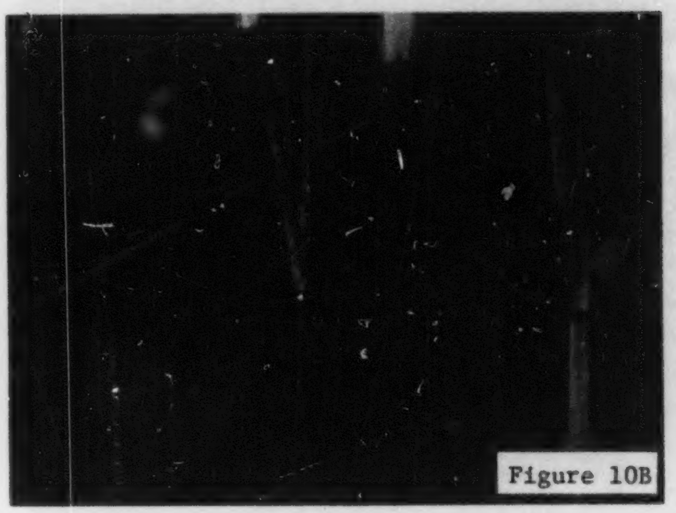

Figure 10B

Table 1A Figures, Page 7 of 8

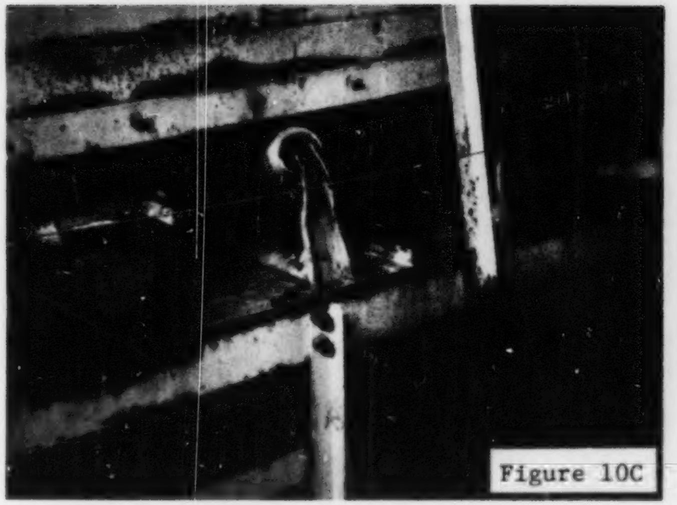

Figure 10C

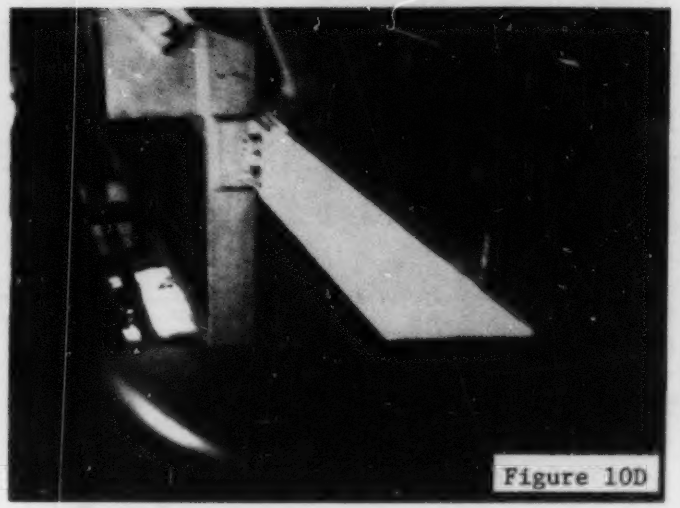

Figure 10D

Table 1A Figures, Page 8 of 8

TABLE 1B. - Measurements of illumination needs of tasks to be seen in exterior spaces of new and old coal preparation plants

Tasks and Location	Munsell Index	% Reflectance	Footcandles 20-30 yr-olds	Footcandles 40-50 yr-olds
1. Active entrances & exits				
New plant				
a) Plant doorway threshold....... (see Figure 1A)	N5	20.4	0.14	1.86
2. Storage				
New plant				
a) Strap steel ends (see Fig. 2A).	N4	12.6	0.21	2.54
3. Coal load/unload areas				
New plant				
a) Edge of column holding........ refuse collector	N4	12.6	3.02	3.73
b) Dump switch.................... (see Figure 3(A-B))	N3	7.1	0.45	0.54
4. Conveyors				
Old plant - unguarded				
a) Emergency shutdown cord.......	N3	7.1	0.03	0.04
New plant - unguarded				
b) Belt edge in tunnel........... (see Figure 4(A-D))	N3	7.1	0.62	0.85
5. Loading platform				
New plant				
a) Chain for loading dock........ (see Figure 5A)	N5	20.4	0.39	0.54
6. Paths/walkways				
New plant				
a) Edge of wheel in path.........	N4	12.6	6.35	9.92
b) Path to phone & dumper........	N3.5	9.7	0.62	0.88
c) Sledgehammer in tunnel........	N5	20.3	1.28	1.87
d) Metal conveyor support in tunnel	N3.5	9.7	0.08	0.10
e) Dark/wet mat in tunnel........ (see Figure 6(A-E))	N3	7.1	1.13	1.55
7. Active tracks				
New plant				
a) Rail switchblade.............. (see Figure 7A)	N4.5	15.9	3.77	5.97
8. Track switch points - active				
New plant				
a) Position of switch handle.....	N4.5	15.9	1.26	1.82
b) Discarded switch handles...... (see Figure 8(A-B))	N4.5	15.9	1.19	1.26
9. Parking lots - new plant				
a) Auto barrier (curb) (Fig. 9A)	N5	20.4	0.37	0.47

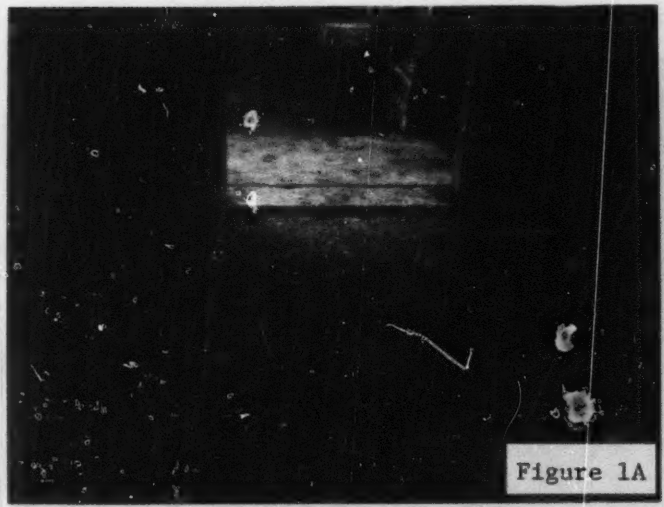

Figure 1A

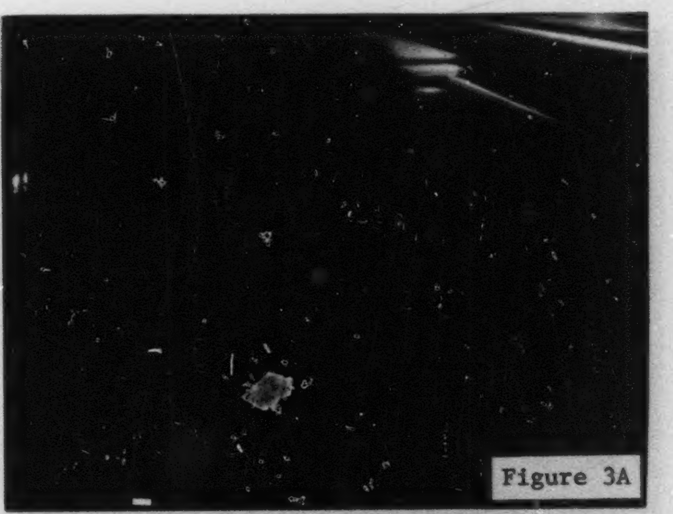

Figure 3A

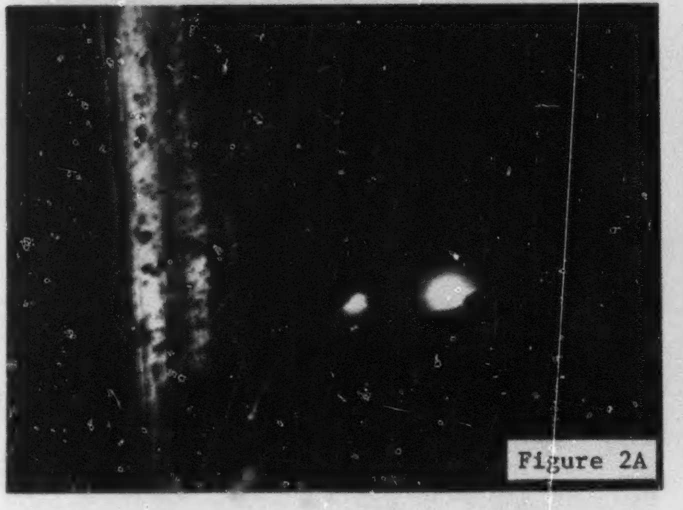

Figure 2A

Figure 3B

Table 1B Figure, Page 1 of 4

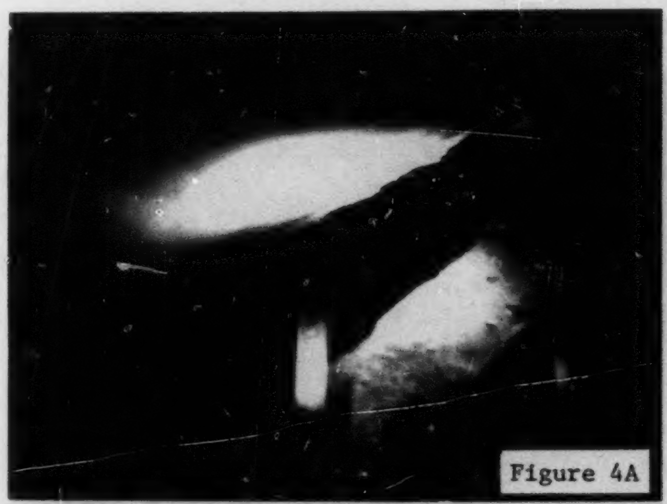

Figure 4A

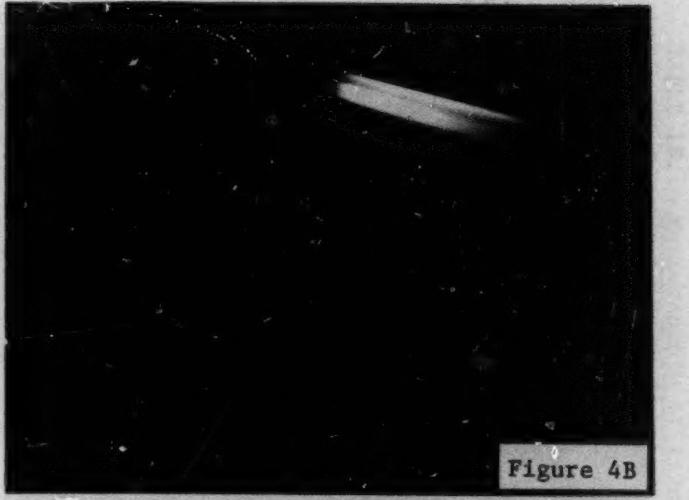

Figure 4B

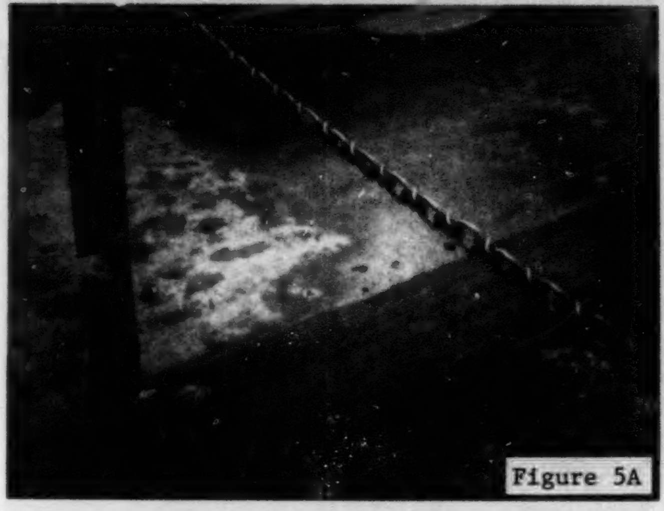

Figure 5A

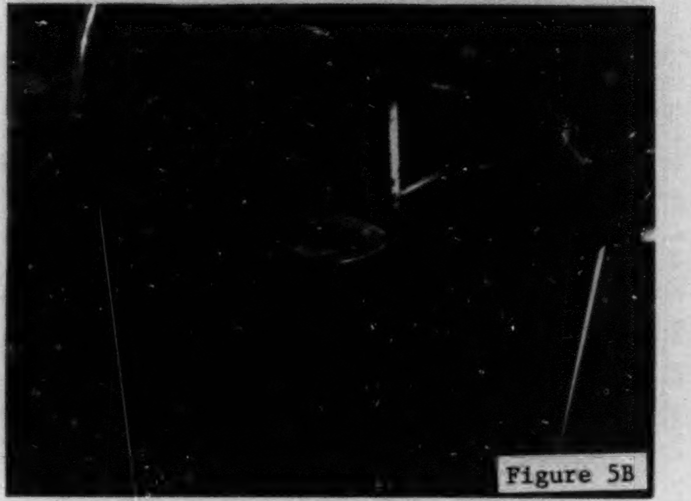

Figure 5B

Table 1B Figure, Page 2 of 4

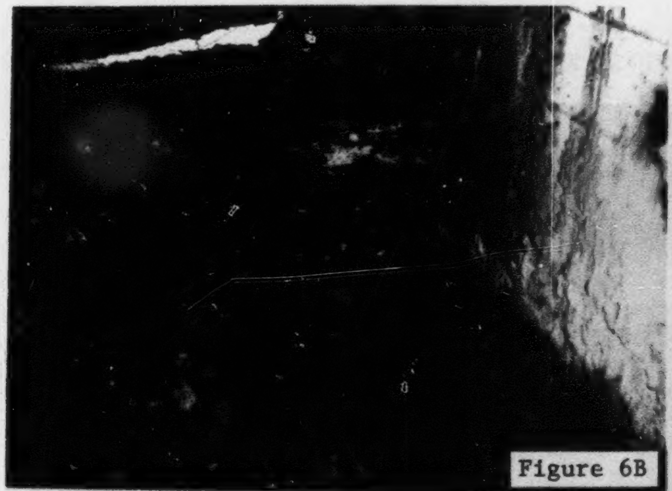

Figure 6B

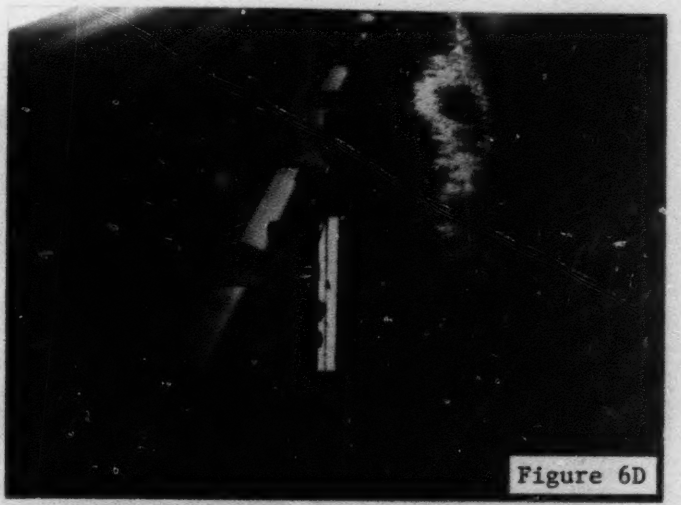

Figure 6D

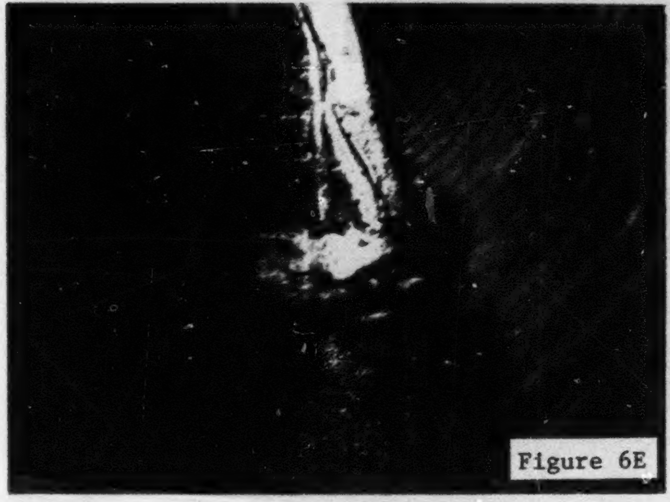

Figure 6E

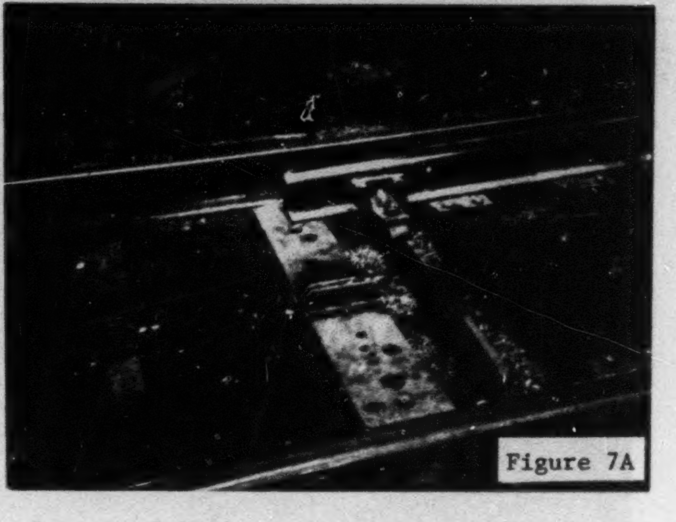

Figure 7A

Table 1B Figure, Page 3 of 4

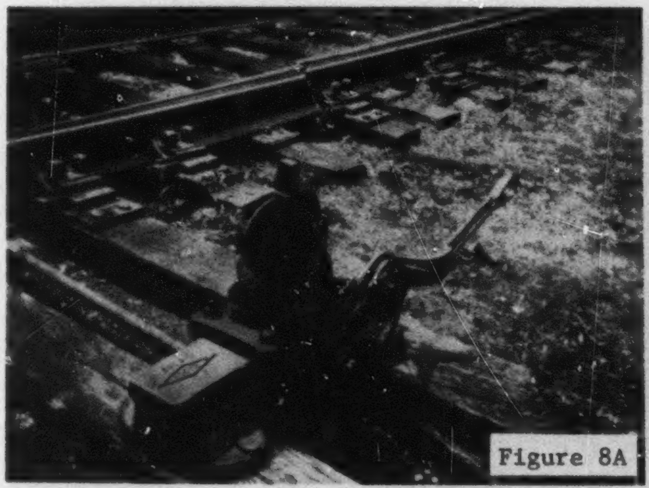

Figure 8A

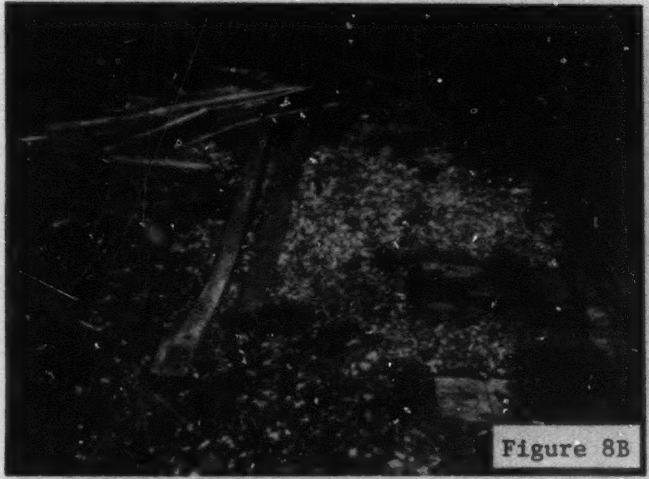

Figure 8B

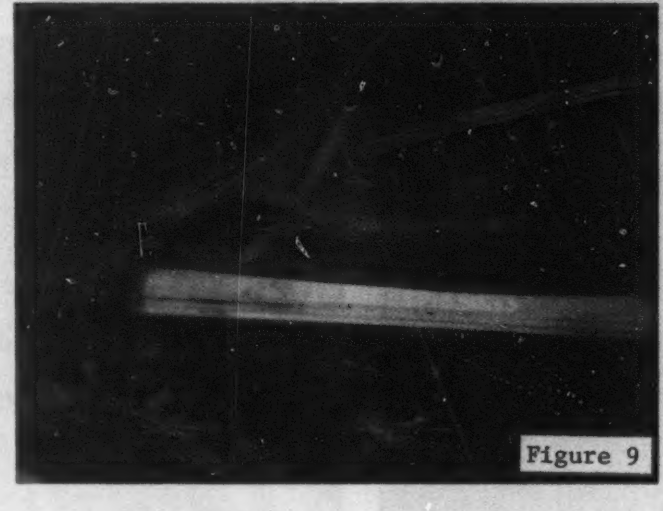

Figure 9

Table 1B Figure, Page 4 of 4

TITLE OF PAPER: Cost Effective Illumination
of Underground Machinery

AUTHOR: Mr. John R. Parker, P.E.
Booz, Allen & Hamilton Inc.
Cleveland, Ohio

Mr. Parker is an Associate, Technology Management Group, with Booz, Allen & Hamilton Inc., and has 12 years' experience designing, developing, and testing mobile, underground mining machinery for original equipment manufacturers. He has had supervisory experience in developing continuous miners, mobile haulage systems, roof bolters, and miscellaneous supply handling and haulageway vehicles. He has a bachelor degree in Mechanical Engineering from Ohio State University, and is a registered professional engineer.

As chief engineer for one company, he was responsible for the selection and integration of illumination equipment into the company's full product line. Since 1979, he has been with Booz, Allen & Hamilton, a consulting firm which has had several Bureau of Mines' contracts to "Demonstrate Coal Mine Illumination Systems." Presently, as a part of one of these contracts, he is working to develop a low-glare illumination system particularly suited to the needs of thin seam, direct current-powered machinery. In this capacity, he has become particularly concerned with the size of luminaire requirements for improved visibility, and the effects of illumination system design on the profitability of mechanized mining operations.

CO-AUTHOR: William F. Hahn, Ph.D.
Principal, Technology Management Group
Booz, Allen & Hamilton Inc.
Cleveland, Ohio

COST EFFECTIVE ILLUMINATION OF UNDERGROUND MACHINERY

by

John R. Parker, P.E.[1] and William F. Hahn, Ph.D.[2]

ABSTRACT

Although supplemental illumination systems have been developed and retrofitted to the nation's underground coal mining machinery, the task of illuminating the work place is not complete because mine operators desire more economical lighting solutions. Mine operators feel that not only were lighting systems expensive to purchase and install, but that costs for maintaining them were higher than expected. In addition, they have seen that new, lower power incandescent luminaires are suited to many mining situations and that these across-the-line systems provided desired hardware and maintenance savings. As a consequence, they believe more economical lighting solutions are feasible.

Unfortunately, many of the lighting system manufacturers are not convinced that more economical systems are feasible. They view low power luminaires as satisfactory only for low seams. Across-the-line systems are considered to be satisfactory for direct current machinery. They feel that their high power luminaires are technically and economically superior for the majority of work place situations.

Certainly operators desire more economical solutions, but significant progress cannot be expected until the mine operator and the manufacturer agree on the requirements for cost-effective solutions. Once there is an agreement, lighting solutions at representative sites can be evaluated and specific recommendations for improving mine lighting can be developed. A collective agreement on these recommendations will result in a master plan for future mine lighting development.

This paper is intended as a baseline definition of the general requirements for cost effective illumination of the work places of an underground coal mine.

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[1] Associate, Booz, Allen & Hamilton, Inc., Cleveland, Ohio.
[2] Principal, Booz, Allen & Hamilton, Inc., Cleveland, Ohio.

COST EFFECTIVE ILLUMINATION OF UNDERGROUND MACHINERY

The Federal Coal Mine Health and Safety Act of 1969 not only required, but started the development of lighting systems which would supplement the illumination provided to the underground coal miner by his portable, battery powered cap lamp whenever he worked in places where fundamental, self-propelled mining machinery was used. Several sizeable projects had to be completed before supplemental lighting systems could be developed and retrofitted to the nation's underground coal producing machinery. These projects addressed the following issues:

- Work place lighting requirements.
- Suitable lamps and power levels.
- Explosion-proof enclosures with windows.
- Circuits to start and run enclosed lamps on mine power systems.
- Machinery compatible lighting systems for all nation's fundamental work place machinery.

These projects have been completed, and the goal of the 1969 Act has been reached as a result of a vigorous and cooperative effort by an industrial team comprised of the U.S. Bureau of Mines, the lighting equipment manufacturers, the Mine Safety and Health Administration, the Bituminous Coal Operators Association, the United Mine Workers of America, and many others. Today, most of the work places where fundamental mining machinery is used are illuminated (see Figure 1) by retrofitted machine lighting systems. These systems were largely comprised of high output luminaires, (high pressure sodium vapor and high or super-high output fluorescent lamps) which are capable of illuminating coal surfaces 3 to 4 meters (10 to 13 feet) away to a minimum reflective light intensity of 0.06 foot lamberts. In addition, some lower power, shorter range fluorescent systems were used extensively on longwall chocks and shields, and some shorter range, incandescent machine luminaires were used on low seam machinery after mid-1979.

Having retrofitted all of their production machinery with supplemental work place illumination systems, and complied with the laws resulting from the 1969 Act, mine operators are now concentrating on their fundamental work task--mining coal profitably. Because most operators feel that lighting systems were expensive to purchase and install, and that maintenance costs were higher than expected, they are searching for ways to reduce the lighting costs on operating machines.

Many operators believe that more economical lighting solutions are feasible for their equipment. They have witnessed the growing use of smaller,

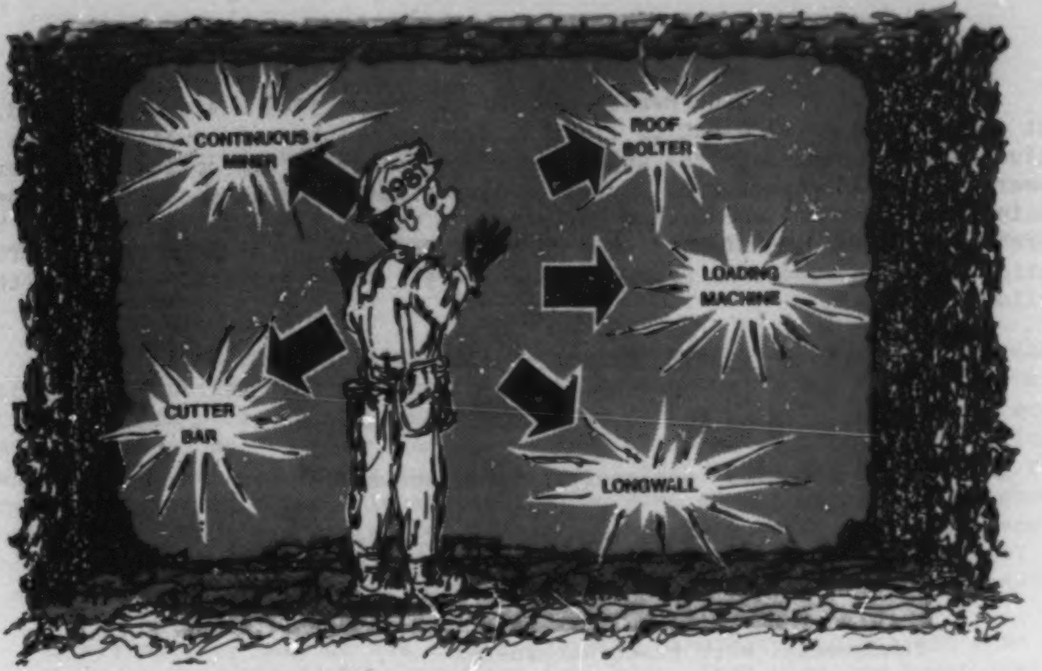
CONTINUOUS MINER
ROOF BOLTER
1981
LOADING MACHINE
CUTTER BAR
LONGWALL

FIGURE 1. - Supplemental work place illumination has been provided.

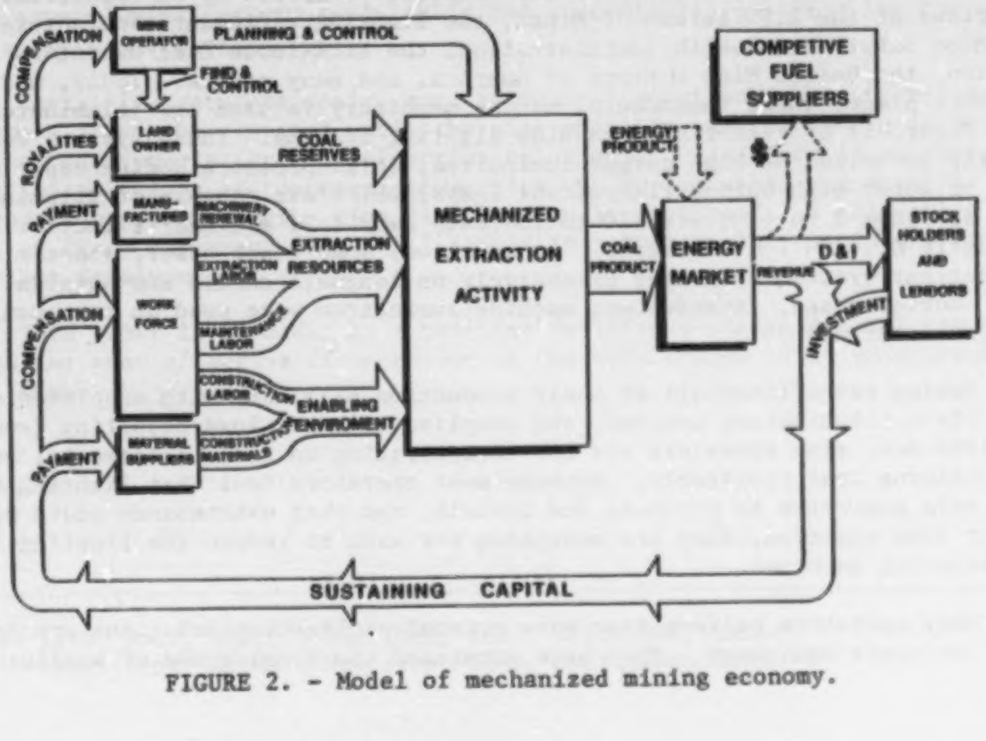
MINE OPERATOR
PLANNING & CONTROL
FIND & CONTROL
COMPETIVE FUEL SUPPLIERS
COMPENSATION
ROYALITIES
LAND OWNER
COAL RESERVES
ENERGY PRODUCT
$
PAYMENT
MANU-FACTURES
MACHINERY RENEWAL
MECHANIZED EXTRACTION ACTIVITY
EXTRACTION RESOURCES
EXTRACTION LABOR
COAL PRODUCT
ENERGY MARKET
REVENUE
D & I
STOCK HOLDERS AND LENDORS
COMPENSATION
WORK FORCE
MAINTENANCE LABOR
INVESTMENT
CONSTRUCTION LABOR
ENABLING ENVIROMENT
PAYMENT
MATERIAL SUPPLIERS
CONSTRUCTION MATERIALS
SUSTAINING CAPITAL

FIGURE 2. - Model of mechanized mining economy.

lower power incandescent systems which were believed to have had insufficient capacity to meet federal illumination requirements and they also feel that these across-the-line systems could provide them with substantial hardware and maintenance savings. Because similar across-the-line incandescents have long been used as mobile machinery headlights and as stationary rail station lights, operators know that additional power boxes containing either ballast or d.c. to a.c. inverters are not necessary, that regulated lamp output isn't necessary, and that smaller, more easily relamped fixtures are feasible.

Unfortunately, most of the mine lighting system manufacturers are not convinced that more economical lighting products are feasible. Many view the use of low power luminaires as satisfactory only for low and thin seam equipment, and the use of across-the-line systems as satisfactory for direct current machinery which cannot otherwise be operated reliably. They feel that their high power sodium vapor and fluorescent systems are technically and economically superior for the majority of work place situations because: 1) more than adequate power allows fewer luminaires to be used, 2) ballasts provide desirable output regulation, and 3) these lamps have substantially longer life.

Certainly mine operators should seek to economize their operations, but it appears that significant economic relief cannot be expected until lighting manufacturers can provide equipment which is clearly responsive to both the technical and economic requirements of a mechanized mining operation. At present, it seems that no economic progress can be expected because lighting manufacturers and mine operators cannot agree on the requirements for cost effectively illuminating the work places of a coal mine.

HOW DO YOU COST EFFECTIVELY ILLUMINATE?

The coal operator will illuminate work places cost effectively when, over the long term life of the machinery, he provides a lighting system which meets the application requirements while holding the costs for providing extraction resources. Surely, lighting systems must be safe for mine use and they must provide effective work place illumination throughout the life of the machine. The costs of providing and maintaining lighting systems on fundamental extraction machinery must be absorbed in the normal long-term costs for providing machinery, operating labor, and maintenance labor.

Figure 2 is a model of the mechanized mining economy. Mechanized extraction activities such as coal winning, coal loading, and roof bolting are fundamental to the business. A coal product results from the use of mining resources which are supplied at a cost to the business. These resources are coal reserves, machinery, extraction labor, maintenance labor, construction labor, and construction supplies. Resources are provided because compensation, payments, and royalties are distributed from the revenues of coal product sales and the investments of stockholders and lenders.

Because supplementary lighting systems primarily provide safety, rather than production benefits, the retrofit of these systems onto extraction machinery was not expected to alter the volume of coal product. Since that product competes with alternative fuels, additional revenues cannot be expected to result from the addition of mine lighting. Consequently, the costs for providing mine lighting must be absorbed amongst the normal costs for providing resources. Since lighting systems affect the costs of providing extraction resources, a mine, on the long term, must provide lighting without incurring additional costs for providing extraction resources. Since machinery and maintenance costs are expected to be higher, extraction labor costs must be lower.

Subsequently, a mine operator can assert that he has provided cost-effective illumination when he has economically met the requirements for applying lighting systems. He has done this when he can assert that:

- Safe lighting systems are used.
- These systems provide effective long-term illumination.
- Extraction labor costs are lower because of lighting.
- Maintenance labor costs are about the same as before lighting.
- Machinery renewal costs are about the same as before lighting.

In the following sections, supporting requirements for each of these key subordinate assertions are developed collectively, these support requirements form a comprehensive guide for evaluating the cost effectiveness of specific illumination systems and for identifying opportunities for more cost effectively illuminating the work places of an underground coal mine.

YOU COST EFFECTIVELY ILLUMINATE WHEN SAFE LIGHTING SYSTEMS ARE USED

The coal operator must provide and maintain safe lighting systems. He has done this when a safe design is used, the Mine Safety and Health Administration (MSHA) agrees that the design, installation, and operation meets federal safety requirements, the appropriate state bureau of mines agrees that state requirements are met, and the system is maintained as designed and approved.

Safe Lighting Systems Are Used When a Safe Design is Used

A lighting system is safe for underground mine use when people are not endangered by the equipment. People must be protected from explosion, electrical shock, contact with hot or moving parts, and blinding light.

Sparks should be prevented from igniting methane. Sparks can be contained within explosion-proof enclosures or limited to low levels which cannot cause ignition.

Coal dust ignition should be prevented. Coal dust buildup should be prevented or diluted with rock dust. Surface temperatures must be sufficiently below ignition threshold - MSHA allows a maximum of 150°C.

High voltage shock protection is required. Contact with shocking voltage potential must be avoided by placing power components within grounded enclosures which can be de-energized when power components must be examined or serviced. Conductor cables must be properly insulated, sized, and maintained. Power devices must limit short circuit current and overload current which could deteriorate cable insulation. Cables must be protected from mechanical abuse.

Personnel should not be exposed to moving parts and hot surfaces. Selective location or mechanical guards can be used to prevent exposure to hot surfaces or moving parts.

Safe Lighting Systems Are Used When MSHA Says Federal Requirements Are Met

A machine lighting system must meet Mine Safety and Health Administration requirements for electrical equipment, 30 CFR 18, and for work place illumination, 30 CFR 75.1719.

MSHA "certifies" explosion-proof luminaires and power system enclosures. Power enclosures must be constructed in accordance with standards and must pass an explosion test. Additional heat tests and mechanical impact tests are used to assure that the mechanical integrity of explosion-proof fixtures will be maintained in service. The MSHA certification asserts that the components are safe for mine use when they are properly used.

MSHA grants a machine "approval" which allows lighting systems to be used. The machine approval is granted to the original equipment manufacturer or to the coal mine operator. The approval establishes the fact that MSHA has reviewed the machine for personnel hazards. Electrically, they have principally confirmed that "certified" power enclosures are used safely, that adequate overcurrent and short circuit protection is provided, and that the machine is properly grounded. Mechanically, the approval assures that guards prevent exposure to moving parts, that cables are protected from damage, and that construction facilitates inspection and maintenance.

MSHA inspects work place illumination. MSHA district inspectors use go/no go meters to establish compliance with the requirements for supplemental illumination as defined for specific machines by

30 CFR 75.1719-1. A minimum surface luminous intensity of 0.06 foot lamberts must be established by the meter when surfaces are at the distances established by the standard. The distance of illumination is established by the machine type, the seam height, the seam width, and machine width. The distance of illumination may vary from 1.5 to 4.5 meters (5 feet to 15 feet).

MSHA gives a prior-to-installation illumination approval. A Statement of Test and Evaluation (S.T.E.) is issued by MSHA when a lighting system is evaluated prior to installation by their Beckley Electrical Testing Laboratory. An S.T.E. is based on incident light readings taken on a machine model inside a coal mine simulator. A machine with an S.T.E. lighting system is not inspected using a go/no go meter unless that system is not properly installed or maintained.

Safe Lighti[illegible]ystems Are Used When State BOM Says State Requirements Are Met

Most of the States with deep underground coal reserves have a department such as a bureau of mines which establishes and enforces state safety requirements. While most have regulations which conform with federal requirements, some have additional or stricter regulations. Kentucky, for example, requires headlights on work place machinery. Pennsylvania has many additional requirements and they conduct an investigation which results in a state Bituminous Face Equipment (BFE) approval. These state agencies should be consulted when new systems are being designed.

Safe Lighting Systems Are Used When the Systems Are Maintained as Designed and Approved

Machinery must be maintained as designed and approved. Mine foremen, federal inspectors, and state inspectors are responsible for assuring that machinery is properly maintained. The explosion-proof integrity of electrical systems is of primary concern because defects are hazardous to the entire mining crew.

YOU COST EFFECTIVELY ILLUMINATE WHEN SYSTEMS PROVIDE EFFECTIVE LONG-TERM ILLUMINATION

A lighting system cannot be cost-effective unless it provides effective long-term work place illumination. This happens when lights operate under expected conditions, the operators of the equipment see better, and future illumination needs can be met easily.

Systems Provide Effective Long-Term Illumination When Lights Operate Under Expected Conditions

The lighting system must be able to start, run, and turn off the luminaires whenever the machine must operate. This can be difficult because the lamps are in explosion-proof enclosures which raise lamp ambient temperatures and because mine voltage sources, particularly direct current sources, are unregulated.

Lamps should start and restart on low voltage. Fluorescent, high pressure sodium vapor and mercury vapor lamps may be difficult to start, particularly when the machine voltage is very low. Enclosed lamps should start at ambient lamp temperatures from 10°C to 100°C (50°F to 212°F). Starting should be reliable at these extremes on low voltage.

Direct current systems must operate on high voltage. Direct current machinery nominally powered at 250 volts d.c., can be expected to see actual sustained voltage in excess of 375 volts d.c. (150%). A constant load (impedance) will draw a higher current (150%) at 375 volts than would be expected at a 250 volt rating. This higher current also increases resistive heat losses by 225%. Since less than a 15% over voltage is normally expected (utility voltage regulation), components must be sized to conduct the additional current (150%) and to dissipate the additional heat (225%) expected when mine voltage is high.

Direct current systems must survive high transient voltages. On d.c. machinery, the motors and long power supply cables store energy when current flows. This energy is discharged whenever contacts open and disrupt the normal current flow. Load voltages can rise several times as a result of this inductive discharge. Power components must survive transient voltage peaks or be isolated from them by adequate surge suppression systems.

Systems Provide Effective Long-Term Illumination When the Operators See Better

As a result of the new illumination system, the equipment operator should be able to see better. This result is not always guaranteed by problem solving methods. For example, some thin seam work places which use wire-rope propelled machinery are exempted from federal illumination requirements because the operator could not see when state-of-the-art lighting systems were installed. Three miners work from roving positions to operate the machines. While coal surfaces were properly illuminated, the luminaires could not be shielded from the miners view. The glare from these direct view luminaires contrasted greatly with the view of ribs and roof surfaces. The workmen were disabled because their eyes could not rapidly respond to the change of view. As a consequence, MSHA exempted these machines until no-glare luminaires are developed.[3]

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[3] The U.S. Bureau of Mines has two contracts which may develop suitable luminaires: J01000084 - Mine Safety Appliance Co.; and J0188077 - Booz, Allen & Hamilton, Inc.

Hazards and task objects should be discernible. Visibility is improved when the miner can readily see hazards and task objects. These are seen when they are discernible from their surroundings. Discernibility can result from a substantial reflectivity difference under low-light conditions or substantial illumination when reflectivity differences are small. Trailing cables, control valve handles, and machine protrusions should be illuminated such that an operator can see them. Visibility can be improved by changing the reflectivity of hazards and objects with paint or color pigmentation. An expeditious application of luminous rock dust to the work place has been suggested as an alternative to high power lighting.

Some visibility problems result from the fact that the reflectivity of work place surfaces may vary as the mine is worked. Coal is a much poorer reflector than rock or rock dust. A high seam work place with all coal surfaces requires a substantial amount of illumination. Appropriate lights may seem to be brilliant when the seam becomes lower, the roof turns to rock, or the roof and ribs are rock dusted to prevent dust explosions. In Figure 3, appropriate shielding and luminaire diffusion improves operator visibility. Additional diffusion is placed on luminaires seen by the operator, nearby luminaires are shielded from view. The continuous miner lighting system shown may be adequate without shields in high seam or work places with coal roofs. The shielding allows the machine operator to see better in low seams with slate roofs.

Field of view should be similarly illuminated. As discussed previously in the thin seam rope-propelled machine example, fields of view must be similarly illuminated for the workers' eyes to readily adjust. Machine operators working from a fixed position can be shielded from viewing luminaires. For others, adaptability is determined by the glare of direct view luminaires. Improved visibility can result from several glare reducing actions.

- Mount the luminaires extremely low--below eye level.
- Use fixtures with lower power, bigger reflectors, and a large source area.
- Use two smaller luminaires to provide required light levels with less glare.
- Raise luminaire background illumination.
- Avoid placing lamps where workmen must look.

Lower glare illumination systems can result from using several of these actions.

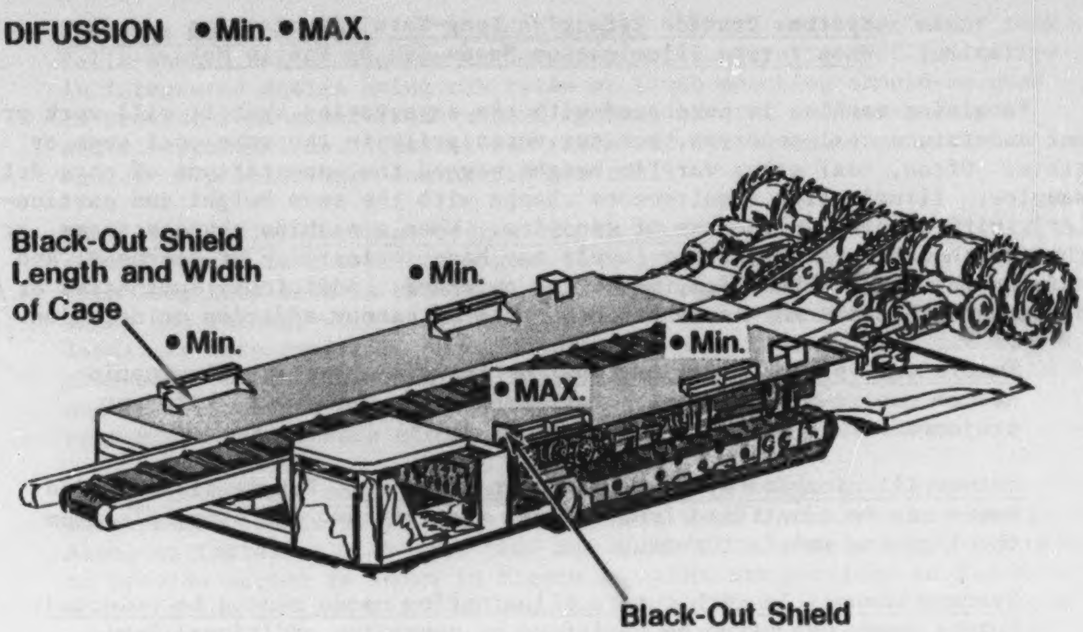
DIFUSSION • Min. • MAX.
Black-Out Shield Length and Width of Cage
• Min.
• Min.
• Min.
• MAX.
Black-Out Shield

FIGURE 3. - Methods of shielding and diffusing luminaires.

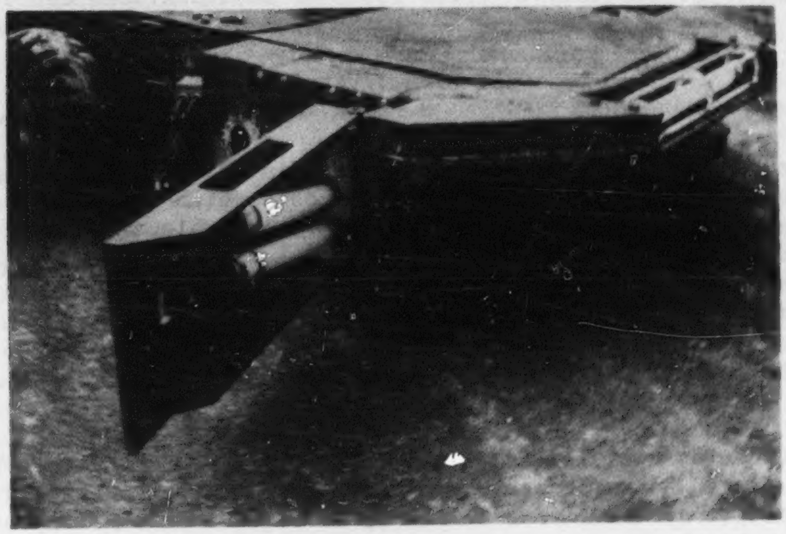

FIGURE 4. - Hinge mount provides access and integration.

Systems Provide Effective Long-Term Illumination When Future Illumination Needs Can Be Easily Met

A mining machine is purchased with the expectation that it will work present and future coal reserves, but not necessarily in the same coal seam or state. Often, coal seams vary in height beyond the expectations of core drill samples. Illumination requirements change with the seam height and particularly with changes in the use of canopies. When a machine changes seams, or the seam height changes, light levels may have to increase or decrease, and shields may have to be added, moved, or extended. Additional luminaires or a different luminaire may be required because of canopy addition or deletion.

Future work place conditions must be known. A better illumination system can result when the future use of the machine is known or projected.

Future illumination system needs must be known. Future illumination needs can be identified from federal regulations, and proposals from the lighting manufacturers.

Systems compatible with future illumination needs should be selected. Future needs can often be satisfied by providing additional luminaires or higher output illumination. Sometimes this is a problem. Additional luminaires may not be feasible in lower seams, particularly when they must be on top of the machine. Future needs should be met by simple modifications such as the addition of a fluorescent luminaire or the removal of one fluorescent and the addition of two sodium vapor headlamps. These types of modifications can be easily made if they were anticipated at the time of system selection.

YOU COST EFFECTIVELY ILLUMINATE WHEN EXTRACTION LABOR COSTS ARE LOWER

Labor costs for coal winning, coal loading, and roof bolting are a substantial part of the extraction resource costs which the mine operator must control. Ideally, extraction labor costs would be lower because of work place improvements. The mine operator can expect lower extraction costs when the addition of lighting systems causes little production delay, and increases the productivity of coal winning, loading and roof bolting.

Extraction Labor Costs Are Lower When Lighting Causes Few Production Delays

A production delay idling two or four miners, and the extraction machine for one to three hours occurs when the explosion-proof integrity of a luminaire is not maintained, when a lamp failure results in a work stoppage, when the machine breaks because luminaire mounting prevented lubrication, or when a luminaire must be removed so a machine can move past a roof timber or work a tight rib position.

Fixtures must be protected against damage. Slate and other minor rock falls should not damage the explosion-proof construction of luminaires. An integrated design using rub rails or flush mounting should be used to prevent luminaires from rubbing against natural and man-made roof and rib protrusions. Guards, rub rails and flush mountings are much easier to provide when luminaires are small.

Some lamp failure/work stoppages can be avoided. Loss of visibility should result in a work stoppage. This production loss can be reduced when long lamp life is realized. Lamps without filaments, or lamps which use strong, well supported filaments are desirable. Fluorescent lamps are more desirable than incandescent lamps. Rough service incandescent fixtures should include spring mounts which absorb shock and rubber pads to damp vibrations. Burn-outs can be avoided by a preventive maintenance effort which prematurely replaces lamps.

Hinged mounts and small luminaires prevent other delays. Access to maintenance points is more easily provided when luminaires are small. Also, an installer with some time and material can hinge mount fixtures to provide access as shown in Figure 4. MSHA has provided an S.T.E. modification program which allows the installer to move a fixture to a more favorable location when simple procedures are followed. Smaller fixtures, particularly smaller fluorescent fixtures, are desirable because they would allow vertical mounting on the sides of machinery. Most fluorescent fixtures are at least 86 centimeters (34 inches) long and cannot be mounted vertically on most machines because only 45 to 70 centimeters (18 to 28 inches) of space is available.

Extraction Labor Costs Are Lower When Increased Productivity Results from Lighting

Increased machine productivity can be expected as a result of supplemental lighting, if the machine can be maneuvered more efficiently at full speed, and the operator is attentive to fundamental mining activities.

Machine maneuvering is more efficient and full speed is utilized. When trailing cables, roof support timbers, co-workers, and the protruding edges and corners of machinery are readily seen, then the machine operator can more efficiently maneuver his machine and can realize the full speed capability of his equipment. These objects are readily seen when they are discernible from their surroundings. As mentioned earlier, discernibility results from either a substantial reflectivity difference under low light, or substantial illumination when reflectivity differences are small. Shields and low glare illumination are necessary to the operator's productive use of machinery.

The operators must be attentive to fundamental activities. Operators make productive use of machinery when they are attentive to the tasks of machine position and other fundamental tasks such as coal cutting, loading, or roof bolting. The operators cannot be attentive when they are concerned about the vulnerability of luminaires, are shielding their eyes, or turning lighting systems off and on. A good lighting system will eliminate operator need for these activities.

YOU COST EFFECTIVELY ILLUMINATE WHEN MAINTENANCE LABOR COSTS ARE ABOUT THE SAME

Coal mining machinery must be compact in order to work within narrow entries needed to stabilize the roof, and along variable height coal seams which follow undulating rock beds. Machinery with either redundant capabilities, or based on large design margins, are uncommon. Maintenance efforts are a substantial part of a mechanized mining operation because the machinery is complex and because it has self-destructive capabilities. In providing machine illumination systems, the mine operator should hope to avoid an increase of his maintenance burden. Provided he is sure that the lighting systems are being used, he will know that maintenance costs have been held near previous cost levels when few service calls are made and when those calls generally require only a modest labor effort.

Maintenance Labor Costs Are About the Same When Lights Are Used and Maintenance Costs Are Low

The costs of maintaining machinery with lighting systems are not known unless the machinery is working and the lights are used. When the machinery and lights are actively used, cost could blossom. An hour meter can establish that lights are being used, but most operators must rely on the work of production supervisors and the knowledge that lamps are frequently replaced.

Maintenance Labor Costs Are About the Same When Few Service Calls Are Made

Maintenance labor costs are low when maintenance is seldom required. Few service calls will be made when the system operates reliably for an extended time, or the production crew maintains the lighting systems.

Reliable system operation results from the selection of a well developed illumination technology. Survival against shock and vibration, over-voltage spikes, rock falls and rib collisions results from the salient features of the selected lamp technology and from the ability of the designers to compensate for shortcomings. Usually, the designers know the salient features, but are unsure of the requirements of the application. Overdesign can be costly, but is often necessary where application data are unknown.

Maintenance by the production crew is possible when simple replacement or preventive maintenance can be done during production delays. Production delays often average one hundred (100) or more minutes a shift. Idle operators or section mechanics may be able to maintain lighting systems when replacement fixtures are on hand and can quickly be exchanged. Cheaper and smaller luminaires could make this possible. Figure 5 shows a small luminaire with a quick packing gland which should allow production crew maintenance.[3] This luminaire, which is being developed under USBM Contract J0188077 by Booz, Allen, can easily be electrically disconnected. Once power has been removed from the machine, the grommet-type packing gland can be opened and the power connector pulled apart. This procedure requires little knowledge of the luminaire. The snap-on polycarbonate guard and diffuser can also be quickly cleaned or replaced by production personnel. Hopefully, high volume production will allow these replacements to be economically stored at each work place machine.

Maintenance Labor Costs Are About the Same When Outside Maintenance Can Service Systems Quickly

When parts are stored in a warehouse outside the mine, or when technical knowledge is necessary to a repair, then outside maintenance labor is required. Figure 6 shows some of the obstacles which must be overcome before outside maintenance can repair work place machinery. Obviously, low maintenance costs are a result of avoiding obstacles.

As shown in Figure 6, the work crew must accurately diagnose the problem, walk to the mine phone and accurately communicate their findings. The outside mechanic must understand that communication, find the right tools and parts, and bring them to the work site - usually about 4 kilometers (2.5 miles) from the warehouse. The mechanic must find a vehicle to transport him and secure a right-of-way to the section. For various reasons, the mechanic arrives late and does not have one essential part or tool. Consequently, that need must be phoned to the warehouse and the part, another vehicle, and a driver must be found before the part is on its way.

Obviously, outside maintenance is inherently slow. Since an outside service call is slow, and is generally coincident with a production delay, outside maintenance should be avoided wherever possible. When it can't be avoided, a production worker should be able to quickly and accurately diagnose the cause of the problem, the parts which should be replaced, and the tools necessary for replacement. Outside mechanics should quickly make replacements and return the machinery to production.

Production crews should be able to quickly and accurately diagnose lighting problems. Since inside parts and system operation is not readily understood, lamp signals (neons or LEDs) should be provided

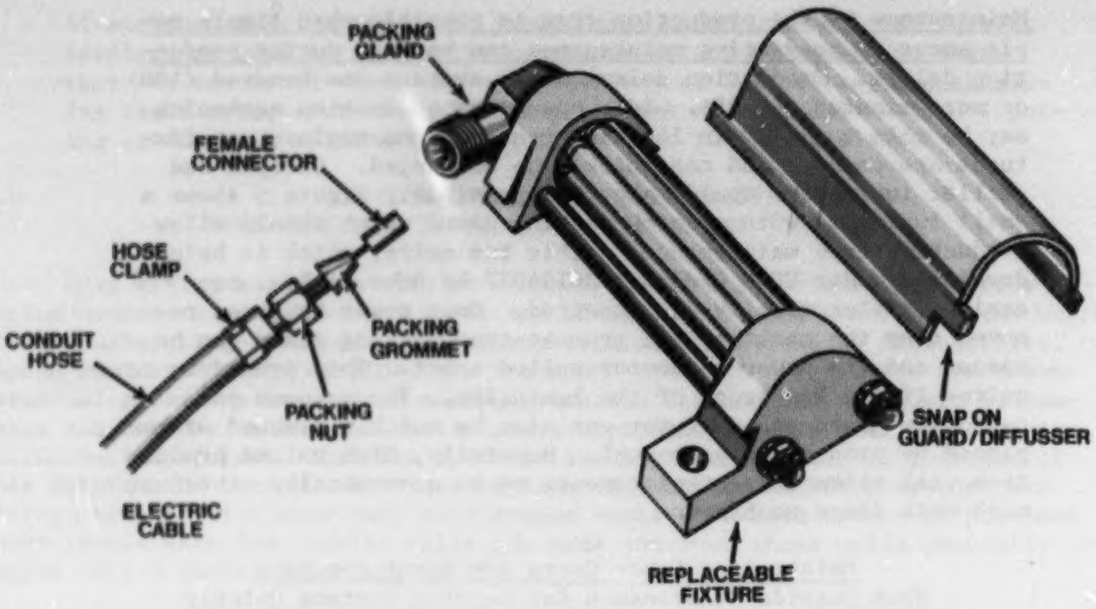
PACKING GLAND
FEMALE CONNECTOR
HOSE CLAMP
CONDUIT HOSE
PACKING GROMMET
PACKING NUT
ELECTRIC CABLE
SNAP ON GUARD/DIFFUSSER
REPLACEABLE FIXTURE

FIGURE 5. - Short, small X-section, quickly serviced luminaire.

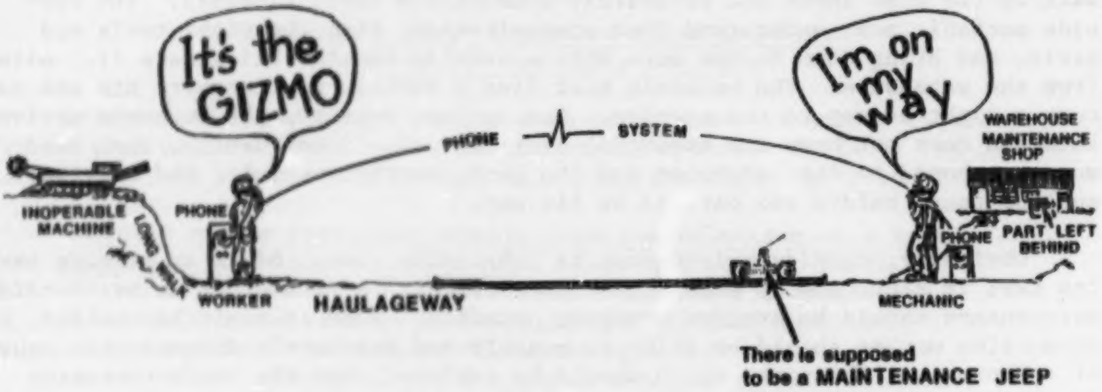
It's the GIZMO
I'm on my way
PHONE SYSTEM
WAREHOUSE MAINTENANCE SHOP
INOPERABLE MACHINE
LONG WALK
PHONE
WORKER
HAULAGEWAY
MECHANIC
PHONE
PART LEFT BEHIND
There is supposed to be a MAINTENANCE JEEP

FIGURE 6. - Obstacles to maintaining machinery.

which can pinpoint modules (luminaires, or power modules) which should be replaced. For example, when luminaires are powered in series, a lamp failure will cause the whole series to fail. Without a lamp signal to pinpoint the cause, the problem could be inaccurately diagnosed as any one of the luminaires or the power system module (ballast) which controls the series. Substantial time and costs could be incurred, should the wrong modules be serviced first.

Maintenance should quickly replace failed modules. Modules, such as luminaires and ballasts, can be tested and diagnosed. Quick repairs are possible when good parts can be quickly exchanged for bad parts. Additional production and maintenance costs can be avoided when repair risks are reduced. Luminaires and power modules should be designed for quick exchange. Repairs should not be attempted when quick exchange with good parts is feasible. Mine operators might expect lighting systems' manufacturers to provide tested modules with compatible interface connections.

YOU COST EFFECTIVELY ILLUMINATE WHEN MACHINERY RENEWAL COSTS ARE ABOUT THE SAME

Machinery has made mining more safe and productive. The abusive extraction process gradually destroys components which are necessary to the survival of mining machinery. The modern mechanized mining operation is dependent on many machines which must be maintained and periodically renewed. The extra parts or renewal parts necessary for machine maintenance and renewal are provided by ongoing renewal parts budgets. Production machinery modifications such as the addition of supplementary lighting systems and operator canopies, are provided as part of this budget. The renewal parts budget must incur the costs of providing new lighting systems, but over the long-term, the cost of providing lighting systems and parts should be a small part of the costs for machinery renewal. This can happen when the costs for renewal lighting parts is low, and the distributed costs of purchasing and installing lighting systems is low.

Machinery Renewal Costs Are About the Same When Lighting Renewal Part Costs Are Low

Machinery renewal part costs cannot be low unless the costs for lighting renewal parts are low. For these to be low, lighting repair parts should be infrequently needed or they should be inexpensive.

Renewal lighting parts should be infrequently required. As discussed earlier, lighting renewal parts will be needed whenever the system fails to operate or the explosion-proof integrity has been damaged. These failures are avoided and renewal costs are lower when a reliable illumination system with durable and integrateable luminaires are selected.

Renewal lighting parts should be inexpensive. When luminaires must be mounted in vulnerable positions, or mine power irregularity prevents a lighting system from being totally reliable, then a lighting system with inexpensive renewal part costs is desirable. Original costs and renewal costs are dependent on how efficiently a manufacturer is able to focus development, manufacturing, sales, and product support efforts on the ultimate solution to mine lighting needs--i.e., a competitively attractive product which is economical to operate and readily available.

- Low development effort. A technology can be inherently expensive to develop into useful products when salient features must be supplemented to satisfy application requirements. D.C. lighting systems which rely on inverters which make high frequency alternating current, and intrinsically safe systems (cannot ignite methane) which must limit voltage and current, are much more difficult to develop than basic ballast or across-the-line lighting systems. Glass lense luminaires withstand higher operating temperatures than do plastic lenses. Small luminaires with tubular globes are much easier to develop, than large luminaires with several windows.

  In developing low-cost luminaires, designers must strive to identify solutions which best utilize salient features of materials and technologies.

- Low unit manufacturing requirements. The manufacturing cost of a product is reduced when the productive advantages of manufacturing processes can be used to replace manual labor. Casting, extrusion, injection molding, stamping, forming, and drawing processes make parts in volume and eliminate manufacturing steps and associated handling, setup, and run requirements. Automation can also reduce costs. High part volumes are not necessary to take advantage of work center manufacturing. Numerically controlled turning centers and milling centers save setup, handling, and run times. Designers must take advantage of manufacturing technologies in their product designs in order for manufacturing costs to be low. Production volumes have a major impact on cost and design as they determine affordable tooling and special automation. Product volumes are highest when the development effort results in a clearly superior product which drives off inferior competition.

- Low application effort supports sales. Product costs include application engineering which is necessary to sell products. Many lighting sales are predicted on a prior-to-installation approval from MSHA, i.e., the system meets federal requirements. The manufacturer must model a machine, arrange luminaires, conduct photometric studies, process a MSHA application, and obtain a MSHA Statement of Test and Evaluation (S.T.E.). This process raises product costs whenever an unfeasible or unattractive lighting system results. Efficient lighting system design requires accurate knowledge of mechanized machines and their operation, as well as knowledge of lighting product capabilities, and federal and state illumination system regulations.

- Low customer support requirements. A manufacturer must have sales, distribution, and service staffs and warehouses. Product costs are lower when significant expansion of staffs and services is avoided. Manufacturers which are adding a product to other lines sold, distributed, and serviced in the mining areas, should have more economical products.

Machinery Renewal Costs Are About the Same When Distributed Purchase and Retrofit Costs Are Low

A lighting system with six to eight fixtures, priced at $400 to $800 per fixture, and requiring 60 to 200 manhours of retrofit installation, is not inexpensive--particularly when retrofitted to a small machine such as a single head roof bolter which is worth only $18,000 to $28,000 new. Obviously, the costs for mechanized machinery are substantially increased unless this $4,000 to $11,000 investment can serve the machine for several years. Machinery renewal costs are lowest when lighting systems are purchased and installed at a low cost and these original products satisfy the mine operations needs for a long time.

Low purchase and retrofit costs are desirable. Original system purchase is usually inexpensive when renewal parts are inexpensive. We have seen that this results from efficient development, manufacturing, application engineering, and customer support efforts which result in competitively attractive products that are economical to operate and readily available.

Low installation costs result when all the mounting materials are provided, the installation instructions are clear and comprehensive, and the installation effort is small.

- All materials are provided. Most manufacturers provide universal brackets for mounting luminaires in common orientations. Hinged and latched mounts and rub rails are not provided because specific machine (not model) knowledge is required. These mounts and guards often would not be needed were luminaires substantially smaller. Some improvements could result if illumination manufacturers made appropriate hinges, latches and basic rub rail designs available.

- Clear installation instructions should be provided. Manufacturers generally supply installers rather than installation instructions. Some installation instructions are found on approval drawings. These usually are confusing because they provide more product information than an installer needs. Dimensioned or scaleable installation drawings can show discrepancies between the designers expectation of the host machine and the actual machine. These discrepancies often result in installation problems (particularly where a S.T.E. does not allow luminaire relocation). Unproductive and costly installation efforts can be avoided when a proposed system is clearly applicable. An operator should examine the proposal before installation is started.

- Installation effort is small. The installation effort is small when the S.T.E. is clearly appropriate without relocating lamps, and when alternate mounts and guards do not have to be designed by installers. Small luminaires allow mounts and guards which are much more economical to fabricate and install.

Long-life systems are desirable. Purchase and retrofit costs can be insignificant when they can be distributed among several years of equipment operation; consequently, a longer system life is desirable. A long system life is realized when premature failure and premature rework is avoided.

- Premature failure is avoided. Original lighting systems will, for the most part, survive provided a reliable power system was selected and the luminaires were mounted integral with the machine or protected by substantial rub rails.

- Premature rework is avoided. Low distributed purchase costs are not realized when a system is replaced prematurely with an alternative system. As a result, rework can be justified only when other savings offset the cost of a second purchase and installation. Since purchase and installation costs are sizeable, rework is to be avoided. In selecting an economical lighting system, a mine operator must be sure that all feasible technologies and configurations were evaluated, developed, and selected.

    - All feasible systems were evaluated. Feasible systems are not always identified or evaluated. As seen with incandescent systems, false assumptions may prevent consideration of some technologies. Other alternatives are not developed because manufacturers have limited development capital and other product interests.

      Hybrid systems using products from several manufacturers may be economically desirable. A simple example is the hybrid lighting system shown in Figure 7, for a Long Airdox roof bolter. This system uses fluorescent fixtures from one manufacturer, with a sodium vapor luminaire from another. This hybrid system allowed Booz, Allen to illuminate a small machine with only four luminaires. The sodium fixture is also a hybrid as Booz, Allen, not the manufacturer, provided the external cage mounted diffuser shown in Figure 8. Although sodium vapor fixtures are marketed by two manufacturers, only one had a luminaire suited to this application. A third manufacturer was the source of the fluorescent luminaire. From this example, you can see that the manufacturer who does not have a full line of products cannot recommend a hybrid system. Consequently, hybrid systems have to be investigated by the potential buyer or someone else.

- Most economical solution was developed and selected. Machinery renewal costs are low when lighting systems are not prematurely replaced. Lighting systems will not be reworked when new solutions are developed. A mine operator will not be faced with expensive, and often repetitive, rework programs when he has taken an active role in avoiding evolutionary obsolescence. He must participate in efforts to rapidly develop ultimate lighting solutions--competitively attractive products which are economical to operate and destined to be available for a long time to come.

SUMMARY OF REQUIREMENTS AND RECOMMENDATIONS FOR COST EFFECTIVE ILLUMINATION

The general requirements for cost effective illumination developed in this paper are summarized in Figures 9 and 10. More economical mine lighting can be expected when and if new products can satisfy more of the many requirements. Most notably, there is a need for:

- Shorter, smaller cross section luminaires.
- Quickly replaceable fixtures using machine stored spares.
- Quick identification and development of clearly economical lighting systems which avoid excessive rework.
- Improved capability to discern hazards and objects from surroundings.
- Low glare luminaires.

Because coal industry segments have different types of equipment and working conditions which present different types of problems, general answers are of limited value. This paper was intended as a baseline for developing a collective agreement between the manufacturers and users of mine lighting systems as they focus on the technical and economic needs of the industry. It is hoped, that from this start, the following efforts will continue.

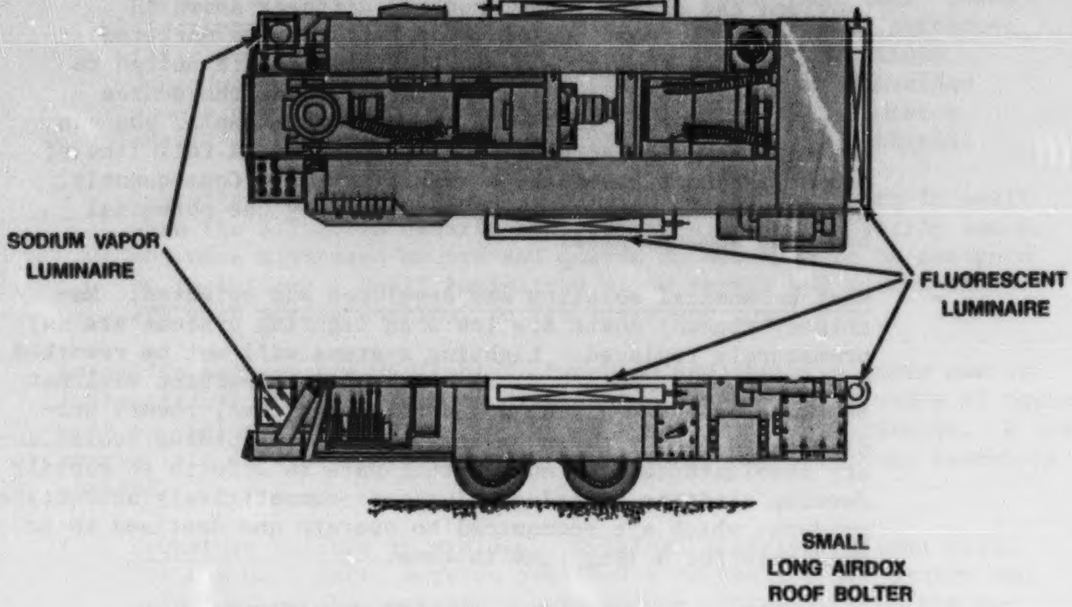
SODIUM VAPOR LUMINAIRE
FLUORESCENT LUMINAIRE
SMALL LONG AIRDOX ROOF BOLTER

FIGURE 7. - Hybrid lighting system from three manufacturers.

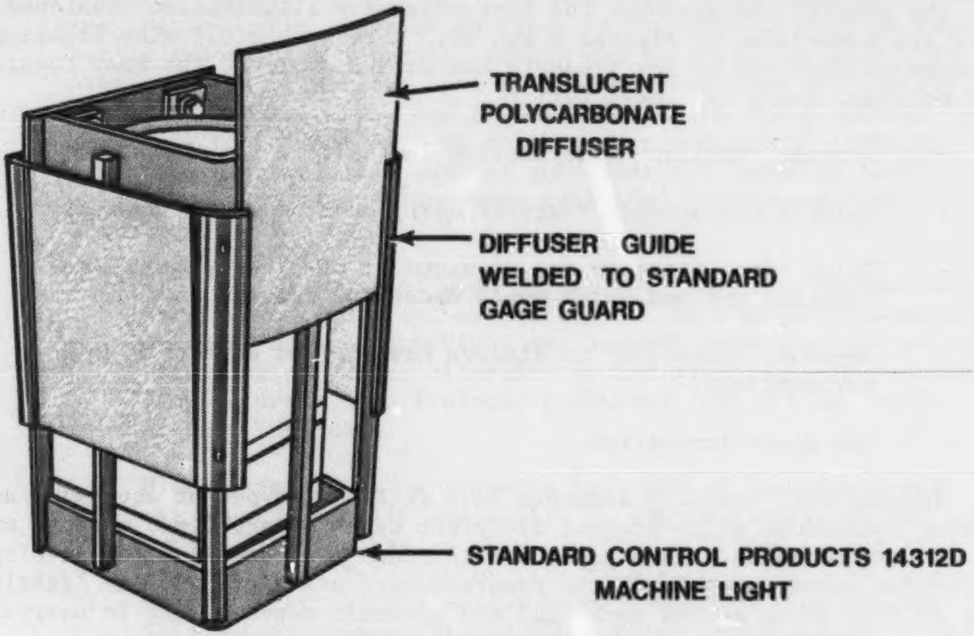
TRANSLUCENT POLYCARBONATE DIFFUSER
DIFFUSER GUIDE WELDED TO STANDARD GAGE GUARD
STANDARD CONTROL PRODUCTS 14312D MACHINE LIGHT

FIGURE 8. - Hybrid luminaire.

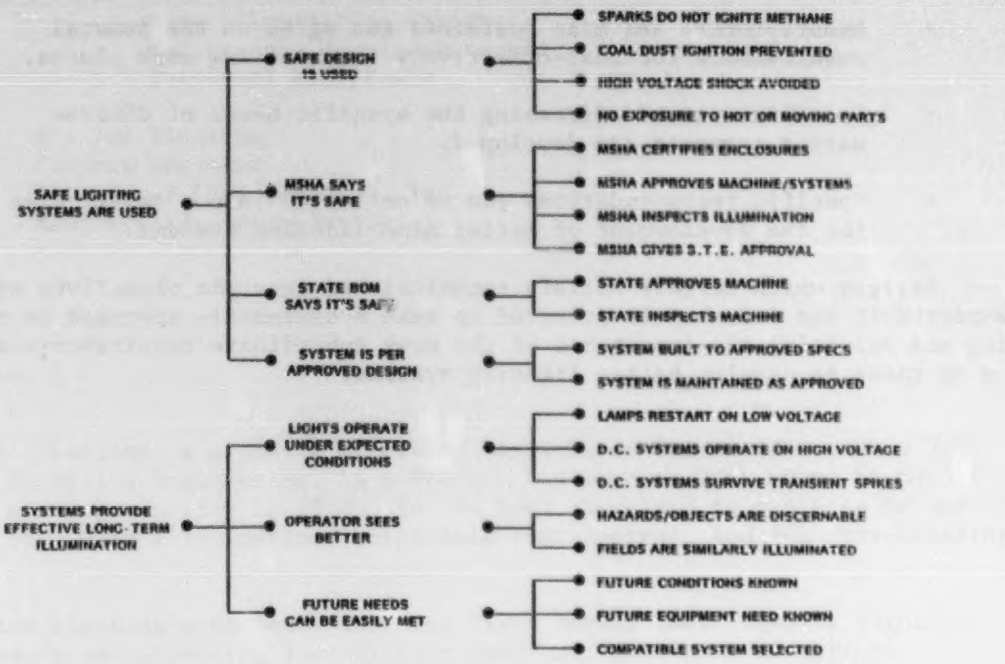
SAFE LIGHTING SYSTEMS ARE USED
SAFE DESIGN IS USED
SPARKS DO NOT IGNITE METHANE
COAL DUST IGNITION PREVENTED
HIGH VOLTAGE SHOCK AVOIDED
NO EXPOSURE TO HOT OR MOVING PARTS
MSHA SAYS IT'S SAFE
MSHA CERTIFIES ENCLOSURES
MSHA APPROVES MACHINE/SYSTEMS
MSHA INSPECTS ILLUMINATION
MSHA GIVES S.T.E. APPROVAL
STATE BOM SAYS IT'S SAFE
STATE APPROVES MACHINE
STATE INSPECTS MACHINE
SYSTEM IS PER APPROVED DESIGN
SYSTEM BUILT TO APPROVED SPECS
SYSTEM IS MAINTAINED AS APPROVED
SYSTEMS PROVIDE EFFECTIVE LONG-TERM ILLUMINATION
LIGHTS OPERATE UNDER EXPECTED CONDITIONS
LAMPS RESTART ON LOW VOLTAGE
D.C. SYSTEMS OPERATE ON HIGH VOLTAGE
D.C. SYSTEMS SURVIVE TRANSIENT SPIKES
OPERATOR SEES BETTER
HAZARDS/OBJECTS ARE DISCERNABLE
FIELDS ARE SIMILARLY ILLUMINATED
FUTURE NEEDS CAN BE EASILY MET
FUTURE CONDITIONS KNOWN
FUTURE EQUIPMENT NEED KNOWN
COMPATIBLE SYSTEM SELECTED

FIGURE 9. - Cost effectiveness tree - application branches.

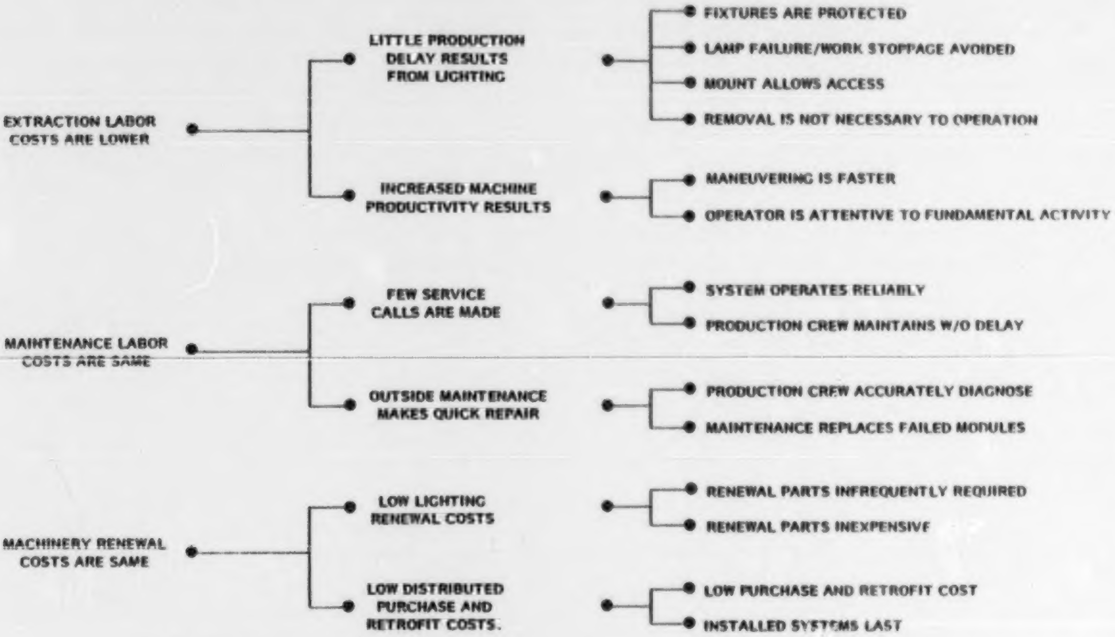
EXTRACTION LABOR COSTS ARE LOWER
LITTLE PRODUCTION DELAY RESULTS FROM LIGHTING
FIXTURES ARE PROTECTED
LAMP FAILURE/WORK STOPPAGE AVOIDED
MOUNT ALLOWS ACCESS
REMOVAL IS NOT NECESSARY TO OPERATION
INCREASED MACHINE PRODUCTIVITY RESULTS
MANEUVERING IS FASTER
OPERATOR IS ATTENTIVE TO FUNDAMENTAL ACTIVITY
MAINTENANCE LABOR COSTS ARE SAME
FEW SERVICE CALLS ARE MADE
SYSTEM OPERATES RELIABLY
PRODUCTION CREW MAINTAINS W/O DELAY
OUTSIDE MAINTENANCE MAKES QUICK REPAIR
PRODUCTION CREW ACCURATELY DIAGNOSE
MAINTENANCE REPLACES FAILED MODULES
MACHINERY RENEWAL COSTS ARE SAME
LOW LIGHTING RENEWAL COSTS
RENEWAL PARTS INFREQUENTLY REQUIRED
RENEWAL PARTS INEXPENSIVE
LOW DISTRIBUTED PURCHASE AND RETROFIT COSTS.
LOW PURCHASE AND RETROFIT COST
INSTALLED SYSTEMS LAST

FIGURE 10. - Cost effectiveness tree - economic branches.

- Manufacturers and mine operators can agree on the general requirements for cost-effectively illuminating work places.
- Specific systems addressing the specific needs of diverse market segments are developed.
- Specific recommendations can be collected into a master plan for the development of better mine lighting systems.

Designs which largely satisfy technical and economic objectives can be expected if the industry is prepared to take a systematic approach to obtaining and weighting the importance of the many subordinate requirements and to using these to develop better lighting systems.

TITLE OF PAPER: Coal Industry Experience with
Mine Illumination Systems:
Maintenance Requirements and
Personnel Acceptance

AUTHOR: Mr. Jon Yingling
Project Engineer
Bituminous Coal Research, Inc.
Monroeville, Pennsylvania

Mr. Yingling, a graduate of Pennsylvania State University, with a B.S. degree in Mining Engineering, is a Project Engineer at BCR, where he has worked since graduating in 1978. He has been involved in projects in underground coal mine illumination, respirable dust control, and industry-training needs.

Mine lighting experience includes field survey investigating lighting maintenance requirements, installation problems, personnel acceptance, status of hardware development, and status of factory integration of systems on face machines.

COAL INDUSTRY EXPERIENCE WITH MINE ILLUMINATION SYSTEMS: MAINTENANCE REQUIREMENTS AND PERSONNEL ACCEPTANCE

by

Jon C. Yingling[1]

ABSTRACT

This paper discusses maintenance requirements of illumination systems in coal mines and personnel acceptance of such systems installed on longwalls and room-and-pillar machines. Specific subtopics addressed are as follows: magnitude of maintenance requirements, mechanical damage, lamp life, electrical failures, electrical troubleshooting, acceptance ratios, frequency of particular acceptance problems, and equipment operators' suggestions for lighting improvements.

BACKGROUND

Under a research program sponsored by the U.S. Bureau of Mines,[2] Bituminous Coal Research, Inc., (BCR) conducted interviews with safety, maintenance, and operating personnel at 60 underground coal mines to assess their experience with illumination systems. The two primary goals of the interviews were to: (1) establish a definition of major installation, maintenance, and personnel-acceptance problem areas to assist the Bureau and other involved parties in determining research and development needs; and (2) to determine successful approaches and techniques for implementing mine lighting in order to establish installation and maintenance guidelines for industry use. This paper is based on the findings of this study.

MAINTENANCE REQUIREMENTS

Lighting-maintenance requirements, in terms of system-reliability levels, repair costs, and production losses due to machine downtime, depend on the system's capability to meet the often extreme mechanical and electrical performance requirements of mine application and on the difficulty of identifying faults and making repairs when system failures do occur. The discussion below addresses the magnitude and nature of these requirements and approaches which show promise in minimizing them.

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[1] Project Engineer, Bituminous Coal Research, Inc., Monroeville, PA

[2] Contract J0308040 "Development of Guidelines for Installation and Maintenance of Mine Illumination Systems"Magnitude of Requirements

Figure 1 shows component-life data on lamps, luminaires, and core-and-coil ballasts which were calculated from inventory-depletion records provided by a number of the studied mines. Table 1 shows the percentage distribution of these mines which realized component service lives of less than 1 year, from 1 to 3 years, and greater than 3 years. These data apply strictly to lighting applications on ac-powered, room-and-pillar, face machines. Scoops and shuttle cars, also included, are both ac and dc.

The data show a surprisingly wide range of realized service lives among the represented mines and an uneven distribution of the population across this range, which is believed to be indicative of a large variability in magnitude of lighting-maintenance requirements from mine to mine. Mine conditions, characteristics of the utilized hardware in view of these conditions, and the protective measures taken upon system installation greatly affect the rate of lighting hardware failures. Various problems can be quite significant at a given mine, but no problems are consistently severe. As shown in Table 1, the majority of mines are realizing component lives in the higher ranges; but, also, a significant minority are replacing components, particularly luminaires, on an annual basis or sooner.

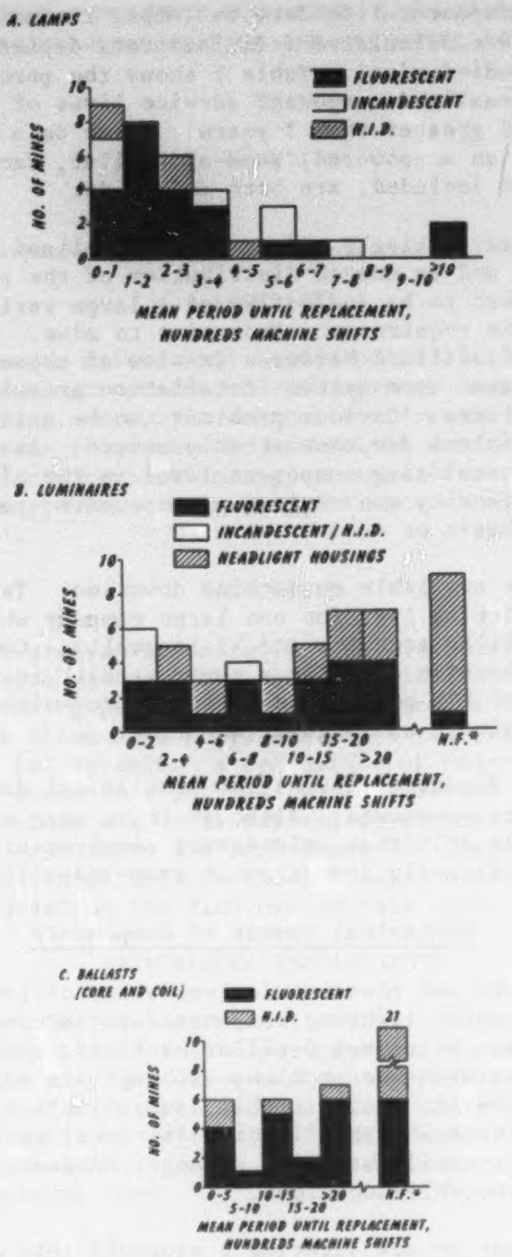
Limited data were available on machine downtime. Table 2 shows total lighting delay-hours during 1980 for one large company which operates approximately 175 room-and-pillar sections and 13 longwalls. Conversion of these figures into lost production costs is a controversial issue, but many mines assume a cost of $15 to $25 per minute of continuous-miner downtime and approximately $100 per minute of longwall downtime.

Except for these downtime figures, no statistical data were obtained on longwall-maintenance requirements. Although there were exceptions, most company representatives felt that maintenance requirements on longwalls were low or moderate, significantly less than on room-and-pillar applications.

Mechanical Damage of Components

Equipment structure and photometric requisites dictate some degree of exposure of machine-mounted lighting components to external impacts, which may result in their damage. On room-and-pillar machines, such damage is the most significant lighting-maintenance problem, although its magnitude varies from mine to mine. Approaches to minimize this damage include modification of machine structure to integrate the lighting fixtures, provision for supplementary external guards, utilization of stronger hardware, and movement of fixtures away from vulnerable locations.

Integration of most or all lighting components into machine profile, via recessing, while concurrently meeting photometric requisites has been shown, in formal demonstration projects, to be technically feasible and effective in reducing levels of mechanical damage. Unfortunately, this technology has not seen widespread implementation in the field. Many operators do not believe integration would be cost effective under their particular conditions



* N.F. - No failures of this type component were recorded during period covered by inventory depletion data.

FIGURE 1. - Distribution of mean component service life values.

TABLE 1. - Percentage distribution of mines by realized component service life

	Percent mines realizing component service lives:		
Component	<1 year*	1-3 years*	>3 years*
Flourescent luminaires.......	39	39	22
HID/incadescent luminaires**.	75	25	0
Headlight housings..........	19	33	48
Fluorescent ballasts.........	17	33	50
HID ballasts................	11	11	78

*at 675 machine-shifts per year

**4 mines only

TABLE 2. - 1980 lighting downtime at one large company*

Application	Delay hours
Miners................	1224
Loaders...............	633
Bolters...............	302
Shuttle cars..........	1586
Longwall	
- Face...............	85
- Head and tail......	20

*175 room and pillar sections,
13 longwalls

(especially in high coal). Others cite that technical reasons have inhibited activity in this area, including (1) uniqueness of machine structure to each model-type or, in many cases, each individual machine; (2) impracticality of making machine modifications to accommodate fixtures in some areas; and (3) uncertainty about maintaining photometrical compliance if modifications were made.

In retrofit/rebuild installations, most recessing activity has been on a "spot" basis, where modifications have been relatively easy and a major need existed. For example, on the continuous miner shown in Figure 2, the luminaires on the machine offside had to be side-mounted because of clearance problems. However, when side-mounted, they were not visible to the machine operator and were being ribbed repeatedly. The illustrated recessing was accomplished by modifying the coverplate structure and making minor machine-component relocations. Recessing was not attempted on the operator's side because the fixtures were visible to the operator and, hence, he was less likely to rib them. Moreover, recessing here would be more difficult due to the presence of the controller box. Exchange of machine-model-specific information on feasible recessing locations, and necessary machine modifications, and assistance in predetermining photometric impact of particular recessing applications could facilitate progress in integration of retrofit lighting-systems.

Another approach, which is more frequently applied than recessing, is the use of supplementary guards, such as bumpers and siderails, to protect the luminaires. These guards have been especially useful on applications of high-profile luminaires in low coal, as illustrated in Figure 3. However, difficulty in finding suitable anchor points for the guards may make installation difficult on some applications. Moreover, the guards are not universally effective; for instance, a high-profile fixture protruding from the side of a continuous miner can be frequently damaged despite the use of substantial guards.

By far, the most common approach taken by the mines to improve durability is the selection of hardware which, because of its design, can better withstand the forces to which it may be subjected. Many mines have discontinued use of fluorescent luminaires and now utilize H.I.D./incandescent fixtures because of their generally more substantial construction. Although the change has frequently proven beneficial, lamp housings on many fixtures are so strong that the luminaire can be driven into the machine by some impacts, causing significant damage to underlying components. Also, in low coal, where potential for roofing and ribbing is generally highest, the high profile of these fixtures limits their application. Protective cage construction is of great importance to the durability of fluorescent fixtures. Many mines have reported large reductions in damage frequency when they use the "heavy-duty" cages offered by manufacturers in recent years. For durability, the cage should be constructed of strong members, and it is best if the mechanical

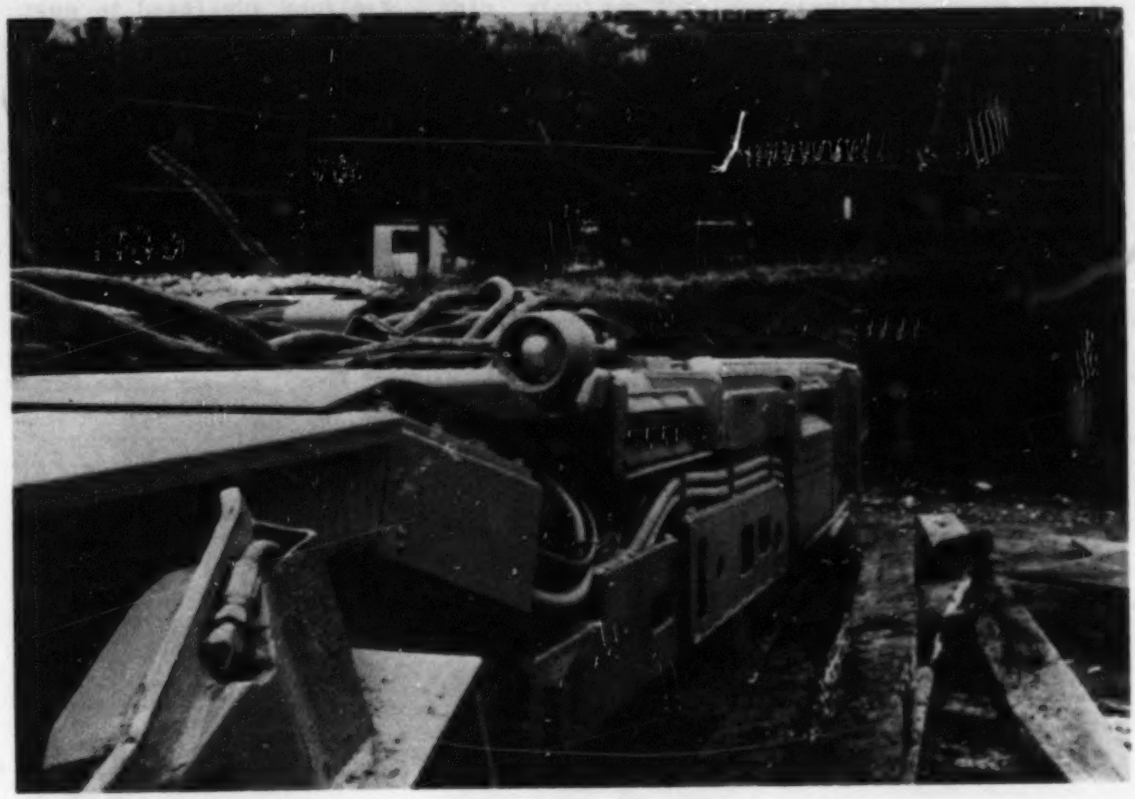


FIGURE 2. - Retrofit recessing of luminaires on low-coal miner.

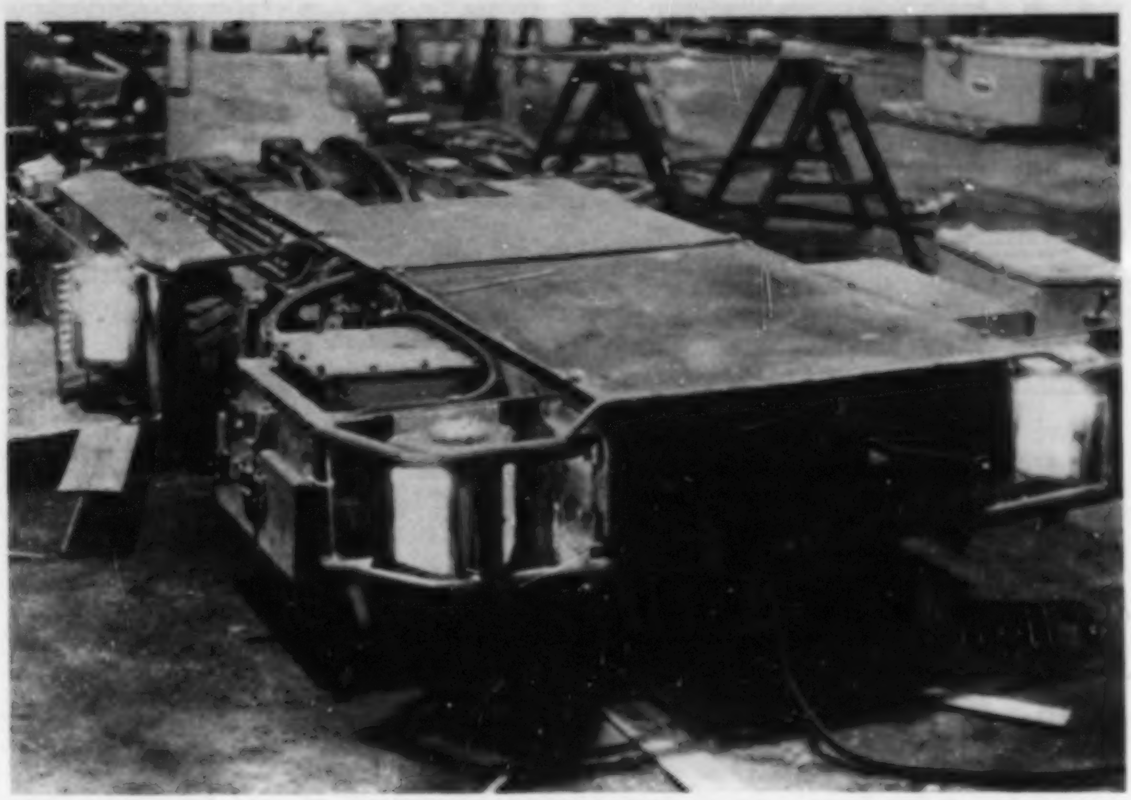


FIGURE 3. - Supplemental guards have facilitated use of high-profile luminaires on low-coal machines.

connection between the cage and luminaire end housings is weak, minimizing stress transfer. Mounting feet should be given great consideration in selection of headlight housings. Thin, aluminum feet are especially prone to breaking and may be difficult to repair. Fixtures are now available with replaceable feet, and field experience with these has been favorable.

Luminaires should be viewed as salvagable items. Damage frequency, extent of damage, and repair costs should be collectively considered in evaluating their durability. Service companies have reported that a 3-to-1 cost differential may exist in average repair costs between competitive luminaires, dependent on materials of construction, design, and parts markup.

At a number of mines, cable damage was reported to be the major cause of lighting downtime. This was attributable not only to the frequency of failure incidents, but to the often excessive times for making repairs. For example, mean downtime for cable replacements on shuttle cars at one mine was over four hours. In most cases, these difficulties can be avoided by careful planning of cable runs. Cables should be routed under machine covers wherever possible and points where the cable could be pinched if the covers are bent should be avoided. Inverted angle iron or pipes might be used for protection where top deck or boom runs are necessary. Sufficient slack should be left at articulation points to avoid fatigue damage. Exposure of cables between the machine body and the luminaire should be minimized through proper routing and selection of appropriate gland orientation (available hardware often places limitations on this aspect). On roof bolters, cables are often damaged by the throwing of supplies on the top deck. Compartments should be provided to facilitate orderly arrangement of supplies in the presence of luminaires and cables. Cable changes are often time-consuming because of the difficult paths through which they must be routed. On some runs, excessive change times can be avoided through installation of J-boxes at strategic locations (for example, on the luminaire side of conveyor crossover-channels) which eliminate the need to reinstall the entire length of cable in the event of failure.

Mine lighting has resulted in a significant increase in application of X/P packing glands in locations where they are subject to damage. Glands are often damaged from slate fall to the exclusion of significant luminaire damage. Experience has been worse with tubing-style glands than with cast, clamp-style glands. Tubing glands are more easily deformed and the cable is more readily pulled through the sleeve.

Gland guards have been applied with mixed results. Frequently, they are structurally under-designed and, as a result, are merely pushed into the gland when impacted. Figure 4 illustrates some successful designs. Care should be taken to insure adequate provision of space for inspection and servicing. Often it is good to mount the guard structure a short distance away from the gland. At this location, it will break the fall of the rock, but, if bent, it will not be forced into the gland. Machine operators tend to use the cable feeding canopy-mounted luminaires as a handhold for exiting the cab, pulling it from the gland. A handle might be installed for the machine operators on the canopy structure to eliminate this tendency.

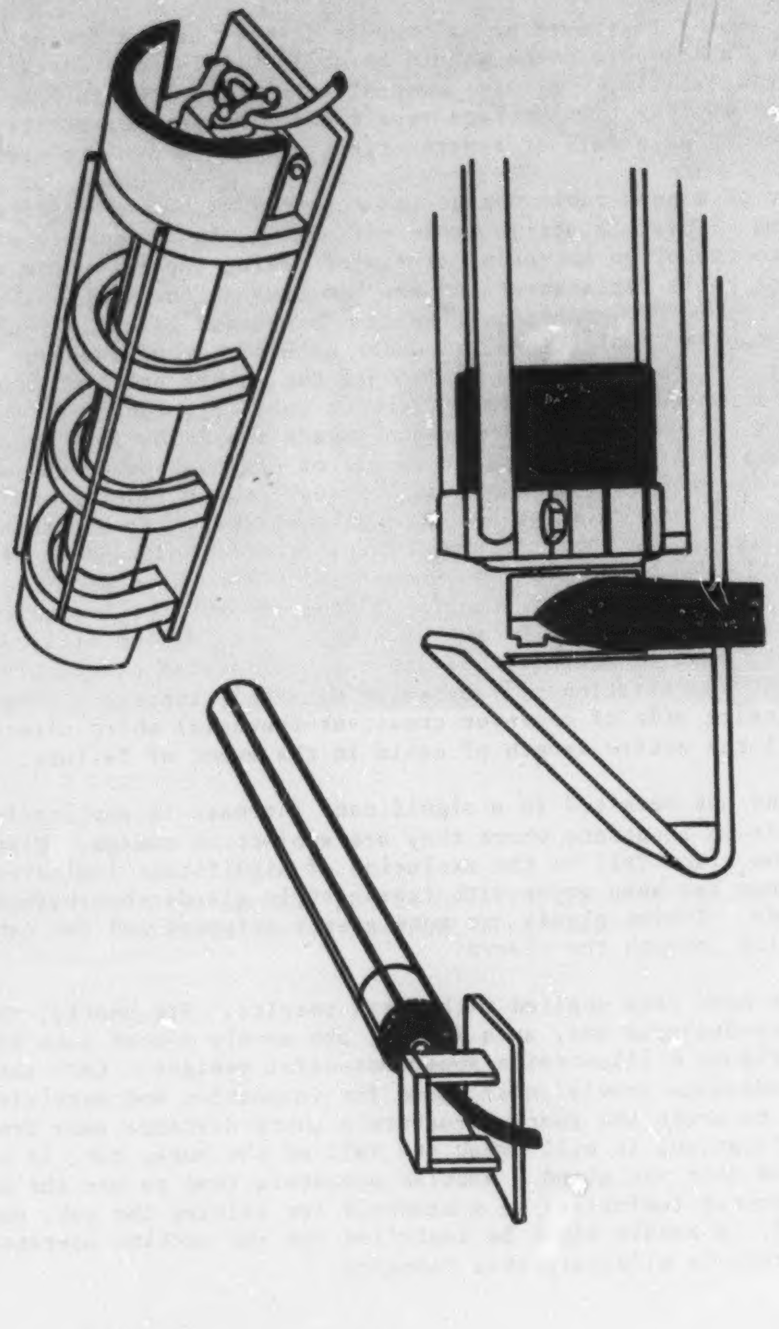


FIGURE 4. - Successful gland guard designs.

The level of mechanical damage on longwalls is significantly lower than on room-and-pillar applications, particularly with respect to luminaires. On most faces it has been possible to locate the fixtures on the canopy (i.e., roof bar) structure, above the walkway or cable trough, where they are subject to few hazards. Face shooting may cause some damage if luminaires are left in place.

A serious problem on a number of longwalls is the frequent incidence of cable damage. Extreme care is warranted in cable routing. Pinch points should be avoided. Sufficient slack should be alotted to permit staggered support advancement, but excessive slack may result in the cable's becoming exposed to the gob or riding under the support base. Slack must also permit the cable to clear, rather than snag on rock accumulated between the supports (especially on chock faces). Cabling requirements vary significantly among the different manufacturers' systems and should be given much consideration in selection of hardware. It may be advantageous to install the system on only a portion of the face (e.g., install only a single power supply or distribution box and associated luminaires) to determine optimum cable routing from experience before wiring in the entire face.

Lamp Life

The study results imply that lamp failure rates are often significant. The primary factors which contribute to premature lamp failure on mine applications are machine vibration/shock levels, and over-/under-voltage drive. Reduced lamp life is most significant on shuttle-car applications where resultant downtime from lamp failures may approach the magnitude of lighting downtime from all causes on continuous miners or other face machines. Also, replacement costs may be significant when H.I.D. or VHO/SHO fluorescent lamps are used or where repair companies are utilized to make lamp replacements, even though they do perform other maintenance services.

Several mines reported extreme life problems with HID (particularly with par-38 high-pressure sodium) lamps. One mine realized an average of only 16 shifts from mercury-vapor lamps, while another 14-mine company realized an average of only 72 shifts from high-pressure-sodium lamps (rated life of these lamps may exceed 10,000 hours). No particular cause of these life problems could be identified nor was the trend consistent; many mines reported excellent life performance from the same type of lamps in similar applications. From the scarce evidence that was obtained, it appears that both voltage regulation and mechanical factors might cause the problems.

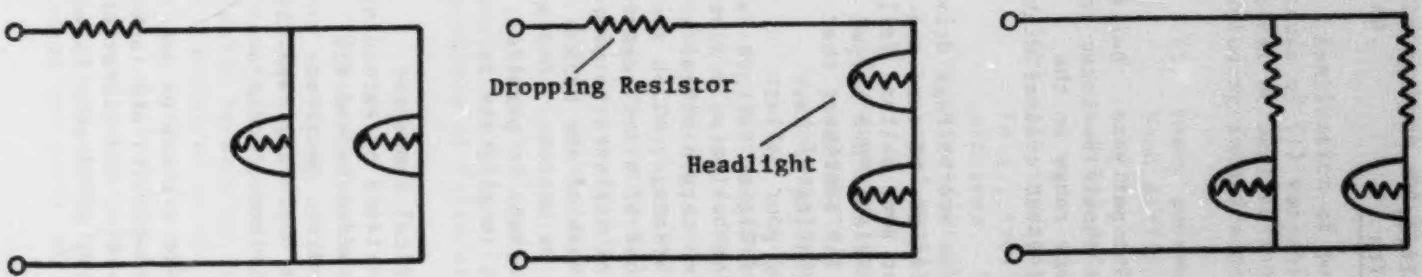
Machine vibration/shock levels can have a significant effect on lamp life. Many mines reported high failure rates in conjunction with rough shuttle-car runways or when continuous miners were cutting rock. Also, both fluorescent and incandescent lamps occasionally fail from mechanical shock when workers pound, or rock falls, in the vicinity of the luminaire. Low-voltage incandescent lamps have larger diameter filaments than their high-voltage counterparts, which increases resistance to breaking from shock/vibration. On shuttle cars, 60 percent of mines using 32 v or lower lamps reported satisfactory lamp life, while only 25 percent of those using higher voltage lamps reported satisfactory life. Incandescent lamps, regardless of voltage, should employ rough-service (RS) filaments. It should be noted that some headlight enclosures in use are approved for only 70-watt incandescent lamps; however, this size lamp is not available with rough service filaments. Finally, shock-dampening features, incorporated into design of the luminaire or in the luminaire mount, have been shown, in some cases, to reduce the level of lamp failures.

On dc shuttle cars, where resistors are used to drop voltage to the proper level for incandescent headlights, lamp-life problems may result if the lamps are wired parallel with each other, but in series with the drop resistor (parallel circuit, Figure 5). This circuit was employed on many early applications because of ease of installation. However, if one lamp burns out, circuit resistance increases, voltage drop across the resistor decreases, and the remaining operating lamp is overdriven, significantly reducing its life, unless the failed lamp is quickly replaced. Other wiring configurations can be used to eliminate this problem, but there are operational or installation problems associated with these. They are shown in Figure 5, with a discussion of relative advantages. Over 80 percent of mines employing the parallel configuration reported major lamp-life problems, whereas only 20 to 30 percent of mines using the other configurations reported major problems.

On longwall applications, the shockwave from face shooting frequently results in lamp failure, even without significantly damaging the luminaires. Although takedown or guarding in the blast zone is permitted under federal law (Section 75, 1719-2(f) CFR), takedown is recommended in cases where face shooting is frequent. Use of a quick-release mounting technique on connector-equipped systems simplifies takedown. Under-voltage-related lamp failures may also be a problem on longwalls. Care should be taken to assure that line losses are not excessive and voltage is being maintained the length of the face.

Electrical Failures

Several factors have been identified which can result in significant electrical reliability problems on both ac and dc machine applications. Poor voltage regulation is perhaps the most important of these. A variable lighting-system supply-voltage can be detrimental to life of all electrical components in the system. One mine, which reportedly experiences up to 25 percent voltage variation at the machine from a nominal 480 vac supply, receives the following mean service lives from system electrical components:



Parallel	Series	Series-Parallel
	Advantages/Disadvantages*	
+ Easy to wire, only three leads required.	+ Easy to wire, only three leads required.	- More difficult to install; 5 or 6 leads required.
+ Isolation of failed lamp simple if one lamp fails.	- Isolation of failed lamp difficult if one lamp fails (neon indicator can reduce problem).	+ Isolation of failed lamp simple if one lamp fails.
+ Second lamp remains in operation if one lamp fails.	- Second lamp does not remain in operation if one lamp fails.	+ Second lamp remains in operation if one lamp fails.
- Lamp life of remaining lamp shortened when one lamp fails unless it is replaced immediately.	+ Lamp life of remaining lamp is not shortened when one lamp fails.	+ Lamp life of remaining lamp is not shortened if one lamp fails.

* + = advantage, - = disadvantage

FIGURE 5. - Alternate wiring configurations for DC application of incandescent headlamp pairs.

	Mean service life, machine shifts
Transformers...........	136
Fluorescent ballasts...	104
Mercury-vapor ballasts.	132
Fluorescent lamps......	74
Mercury-vapor lamps....	16

Replacement cost of these components is $4,865 per machine per year. Ballasts differ in their sensitivity to voltage variations. Care should be taken to insure they are compatible to the actual operating voltage range on the machine. Under extreme operating voltage ranges, incandescent systems might be most appropriate.

In addition to heat-induced failures of ballasts from overvoltage drive, other conditions have resulted in significant rates of failure of core-and-coil ballasts. Improper wiring connections accounted for some ballast failures, particularly on 6-lead or multi-tap units, but experience has helped to minimize this problem. A number of operators expressed the sentiment that some manufacturers have done an inadequate job of heat-sinking or have increased the potential for heat-related failure by using poor ballast packaging arrangements. (For example, operators reported higher failure rates of those particular ballasts which are surrounded by other ballasts.) A very significant number of mines reported that the mounts which secure ballasts within the enclosure are subject to frequent mechanical breakage, which frees the ballasts and permits shorting. Finally, a large number of mines reported frequent, short-induced ballast failures. The tendency of ballasts to overheat when lamp leads are shorted depends on design. Because of the high incidence of cable damage at some mines, these rates can be extreme. One mine using a new fluorescent ballast design, which drives two lamps in parallel, reported making 250 replacements over a matter of months, largely due to shorting incidents.

Transformers were generally a non-troublesome electrical component. However, a surprising number of mines did report the experience of exceeding transformer kva capacity when additional headlights were added beyond STE specification to increase face lighting on continuous miners. Operators should check to see that the existing transformer has the necessary capacity before adding headlights. Also, on low-voltage lamp additions, conductor losses should be considered.

Identification of failure causes on intrinsically safe systems on ac applications proved more difficult because of increased complexity and lack of diagnostic effort at the mines. Voltage regulation, moisture, and vibration-induced failures were reported. No significant reliability difference between these systems and the simpler, conventionally-ballasted X/P systems was indicated.

Application of power-conditioning systems on dc is much more difficult because of (1) variability of supply voltage over a much wider range than a typical ac application and (2) frequent high-voltage transients. Our findings (excluding incandescent systems) indicate:

(1) Power parameters and, hence, reliability of system performance have been difficult to predetermine prior to installation. Manufacturers are frequently "custom tuning" their systems to local conditions on a trial-and-error basis.

(2) All investigated systems applied where mine distribution was dc (e.g., trolley line, dc cable) experienced severe reliability problems. Conversely, many successful applications were found where mine distribution was ac and the dc originated at a load-center-based rectifier.

(3) Some failures could be avoided if operators always turned the systems off during low load periods (e.g., during crew changes) when voltage tends to rise.

No major electrical problems were identified for incandescent applications on ac or dc machines. Because of low cost; simplified installation, troubleshooting, and repair; better operation and less damage under fluctuating voltage conditions; and a change in enforcement policy which facilitates use of lower output lamps on face machines, these systems have considerable popularity among mine operators and are seeing increased application on both ac and dc machines in both low and medium seam heights.

Electrical reliability of longwall systems was reported to be good. No consistent failure trends were reported from mine to mine except for some incidence of failures related to cable damage.

System Servicing and Fault Isolation

Several features can be implemented during system installation to facilitate servicing of the illumination system and to prevent interference with machine servicing. Power-supply boxes should be located at protected, but accessible, locations. (Tram cab installation, however, is usually undesirable because of the discomfort it causes for machine operators.) Location of luminaires on machine covers over frequently accessed machine components (e.g., hydraulic reservoirs) should be avoided if possible. Also, additional cable slack should be provided to permit the machine covers to be set aside without removing the luminaire. Ouick-release mounting brackets are useful in situations where luminaire removal is necessary (e.g., the fixture must span across two cover pans). Figure 6 shows a simple design which is not easily

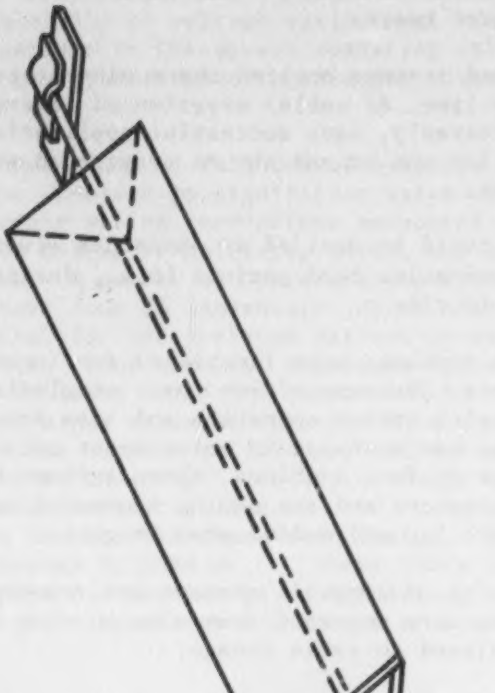


FIGURE 6. - A quick-release mount for fluorescent luminaires.

damaged by bending. Some mines refabricate machine covers to accommodate the luminaires. Hinge brackets should be used on recessed luminaires to facilitate lamp changes.

Numerous hardware-design features also affect ease of servicing. Slip-fit glands may facilitate gland removal on some X/P enclosures, where, if threaded glands are used, adjacent glands must be removed to gain access to the one to be removed. Lamp-changing procedures vary significantly between different fixture designs. If lamp-changing is to be performed at the face, use of fixtures posing difficulty should be avoided. Slip-fit packing glands and connectors greatly facilitate luminaire change-out. Ballast packaging arrangements also vary significantly between different manufacturers' designs, and they should be examined to assess the difficulty of changing out the ballasts or accessing them when making electrical tests. One mine has modified their controller boxes to house the ballasts on a swing-out panel.

The difficulty of isolating electrical faults is highly dependent on system design. As expected, few mines reported troubleshooting problems with incandescent systems, not only because mine personnel are familiar with the systems, but also because of their inherent circuit simplicity. Somewhat surprisingly, more mines reported troubleshooting difficulty with core-and-coil ballasted systems than with the more complex electronic systems (primarily, intrinsically-safe systems). From the comments of mine personnel, it appears that design of the electronic systems facilitates isolation of routine failures (once maintenance personnel gain some familiarity). Nonetheless, it should be noted that a small number of mines discontinued use of the electronic systems because of frequent electrical failures and extreme troubleshooting problems. When mine-power parameters are poor, resulting in frequent and varied failures, the complexity of the electronic systems may be a disadvantage.

The most frequently cited troubleshooting problem on conventionally-ballasted systems results from use of dual-lamp ballasts which drive the lamps in series. A number of common failures (burnt-out lamp(s), bad ballasts, etc.) result in the same obvious manifestation--the lamps on the circuit do not light. Resolution of the ambiguity requires performance of a series of tests which may involve considerable time.

Both electrical troubleshooting and component replacement are greatly facilitated on systems employing plug-type connections between individual circuit components or groups of components. Specific advantages of this design aspect include:

(1) During electrical troubleshooting, circuit redundancy is an easily-used advantage. Leads can be easily switched to an existing duplicate unit to test a suspect one. Similarly, a suspected faulty unit is physically easy to replace with a new unit.

(2) When components are grouped (e.g., luminaire/integral ballast/ connector), fault isolation within the group need not be done at the face. Rather, the entire group can easily be changed-out, minimizing machine downtime.

(3) When line-installed connectors are used, cable continuity checks are facilitated. (This is particularly important on longwalls, where cable failures are frequent and check procedures tedious.)

Integrally ballasted, connector-equipped, X/P fluorescent luminaires which were originally designed for longwall application are now seeing some application on mobile face machines. Advantages over standard fluorescent fixtures include (1) the single ballast-to-lamp-ratio facilitates troubleshooting, (2) distinction between failed ballasts and lamps at the face is unnecessary, (3) luminaires are readily changed out, and (4) need for a separate X/P enclosure to house the ballasts is eliminated. When applying these systems, care should be taken in establishing pigtail lengths. Standardization on a single pigtail length may not be desirable if protected cable runs are to be maintained.

PERSONNEL ACCEPTANCE

During the study, 384 machine operators were interviewed concerning their evaluation of the illumination systems on their machines. A consistent line of questioning was employed; and they were asked about their overall appraisal of the system, existence of several specific problems, and suggestions for improvements.

Overall Acceptance

On room and pillar applications, 74 percent of the machine operators viewed favorably the systems on their machines or the machines they interface with. A majority of machine operators expressed a favorable overall opinion regardless of the particular type of machine or the seam height of the application. On longwalls, general acceptance was even higher, with 96 percent of the face-crew members expressing an overall favorable opinion.

Acceptance of the systems on room-and-pillar machines was shown to increase with length of the operator's experience with the system, as shown in Table 3. This implies that a period of adjustment was necessary for many of the machine operators before they began to like the systems; this implication was further supported by numerous comments made to this effect by the machine operators.

No significant difference in the overall appraisals of the machine operators was found when comparing acceptance of fluorescent, H.I.D., and incandescent systems. Excluding shuttle-car operators, machine operators expressed favorable opinions of 66 percent for fluorescent, 66 percent for H.I.D., and 63 percent for incandescent systems.

TABLE 3. - Percent acceptance versus lighting experience

Years experience with mine lighting system	Percent favorable overall appraisal
0.0 - 1.0.......	61
1.0 - 2.0.......	65
2.0 - 3.0.......	70
>3.0.......	82

Acceptance decreased somewhat in lower seam-height applications, as shown in Table 4. However, the difference in acceptance was less than expected, particularly between applications in seams higher or lower than 42 inches. It was significantly less than that found in the Joint Committee (UMWA/BCOA/MSHA) Survey of 1978. Possible reasons for the difference between the surveys include modifications in system design as a result of the changes in enforcement policy which followed the 1978 survey and the fact that the machine operators have had several additional years to become adjusted to the systems. Regardless of the reason, the improvement in low-coal operator acceptance is welcomed.

TABLE 4. - Percent acceptance versus seam height

Seam height, meters (inches)	Percent favorable overall appraisal
≥2.44 (96)	86
1.07-2.44 (42-96)	74
≤1.07 (42)	69

Specific Problem Areas

A favorable appraisal of face-illumination systems does not preclude existence of significant problems. Luminaires covered with rags, paint, etc., are evidence of this. On room-and-pillar machine applications, numerous individuals, including many of those who expressed a favorable opinion of the system on their machine, complained that the system (1) caused them discomfort or impeded performance of certain visual or manual tasks when working around the machine, or (2) did not optimally address their lighting needs for task-performance or safety.

Glare-related complaints were most frequent. Excluding shuttle-car operators, 57 percent of the equipment operators cited a glare problem with at least one luminaire on their machine. The majority of complaints cited luminaires in close proximity to the individuals' normal work station(s). The frequency of these complaints was independent of the type of light source (fluorescent, H.I.D., incandescent). However, of the smaller number of complaints involving luminaires remote from the normal work stations, point-source lamps (incandescent and H.I.D.) were cited with much greater frequency.

Overall, the difference in the frequency of glare problems in the different seam-height ranges was not major, although there were differences for certain machines.

On continuous miners, glare complaints most frequently involved the luminaire(s) on or immediately inby the operator's cab. A smaller, but significant, number of complaints involved the machine headlights. On retreat sections, men frequently work inby the machine when setting posts, and headlights, if left operating, can be particularly glaring.

The most common glare complaints on roof bolters involved (1) luminaires near the drill head, which bothered operators and helpers when drilling or performing helpers' duties, and (2) luminaires on or near the machine deck, which bothered operators when preparing bolts and changing bits and obscured vision of materials on the machine. Complaints were much more frequent on dual-head than single-head machines, but most luminaires cited in the complaints on dual-head machines bothered the operators only when intermittent tasks were performed. Many problems with luminaires mounted in the vicinity of the drill station on single-head bolters appeared particularly severe.

The incidence of shuttle-car operators reporting glare problems with miner- or loader-mounted fixtures was insignificant in high seams but much more frequent in low (<42 inches) applications. On cutters, loaders, and face drills, most glare problems occurred when operating from the cab, from fixtures in the immediate cab vicinity.

Illuminated machine vicinities are typically the only lighted areas at the working face. When approaching or leaving these vicinities, workers' eyes must adjust to different brightness levels. The change can be abrupt (e.g., when passing through a check curtain) or more gradual. Overall, the proportion of individuals who indicated this posed problems for them was low. However, the incidence of the adaptation problem was significantly more frequent on (1) low-coal machines, and (2) dual-head bolters. Dual-head bolters, because of large machine dimensions relative to the mine entry, often require a larger number of luminaires to meet photometric compliance; and it is likely that the generally higher brightness levels increase this problem on these machines.

Visible airborne dust and water spray often create a foglike condition around continuous miners. Light, primarily from machine-mounted headlights, reflects off the dust and spray cloud creating a glaring condition called "whiteout" which inhibits visual observation of the working face and other surfaces. When the dust cloud spreads to the outby portion of the machine (generally, only under unusual circumstances), light from the area luminaires contributes to the condition; in this case, vision is particularly impaired. Forty-three percent of the miner operators stated that the whiteout condition significantly inhibited their vision.

With increased light levels after implementation of machine-mounted lighting systems, contrast between the cap-lamp beam and surrounding surfaces is diminished, presumably reducing the effectiveness of the cap lamp as a means of signaling coworkers. Only 12 percent of the machine operators thought this was a significant problem. The following circumstances appear to affect the seriousness of the problem:

(1) Direct Eye Contact - Operators indicated that when they can see the beam directly, there is no problem, but difficulty is increased when they must rely on reflected light. Accordingly, on some machines, the frequency of signaling problems was much higher in low seam heights where direct eye contact is difficult, and frequency was also higher among shuttle-car operators with offside cabs.

(2) Anticipation - Operators commented that the problem is more significant with unexpected than anticipated signaling.

Other problems cited with generally low frequency include (1) obstruction of visual avenues by the presence of a lighting fixture, (2) "hindrance-related" complaints where lighting fixtures are frequently bumped, physically interfere with performance of some tasks, or inhibit cab ingress or egress, and (3) heat complaints. A common practice in low coal, which should be avoided because of the serious discomfort it causes machine operators (because of heat and crowding), is location of luminaires or power supply enclosures on cab decks.

Finally, machine operators have noted several cases where improved lighting is desirable to meet their needs for task performance and monitoring of conditions. The most common recommendations are shown in Table 5.

Approaches to Minimize Acceptance Problems

Shielding and diffusing techniques are employed most frequently to control glare problems. Shields must take into account the operator's various lines of sight to the fixture which, in turn, depend both on the particular work task in question and the work habits of the operator. Operators have suggested that adjustable shields be used to accommodate these variations.

Changes in fixture location have frequently been made with great success. In particular, great care should be taken in location of fixtures on canopy or TRS structures on roof bolters. Often great improvement can be realized with minor relocations. Canopy-mounted fixtures on continuous miners are difficult to locate without being a glare problem, but several mines reported that glare problems are diminished if the fixtures are located as far toward the outby end of the cab as possible. Modification of canopy structure to recess the luminaire can diminish the problem for the operator, but companies are often reluctant to do this lest the approval status of the canopy

TABLE 5. - Areas where machine operators recommended more/better illumination

Machine	Area	Comments
Continuous miner	Face	- Greater light intensity on the face is desirable and "better" lighting is needed to penetrate dust and spray. Primary concern is definition of coal marker beds and position of cutter bits to facilitate cutting operation.
	Inby roof	- Should be illuminated at higher level to monitor roof conditions.
	Tail area	- Higher illumination level is desirable to reduce abrupt change in light levels when looking toward shuttle cars while loading. - A separately switched headlight directed at offside rib and floor would be desirable for backing up machine. - Improved visibility of tail boom desired to facilitate aligning of shuttle car with machine.
Shuttle cars	Inby/outby	- Dual headlights generally preferred over single headlights because offside light improves positioning of vehicle relative to entries. - Headlights often mounted in poor locations where they quickly become covered with mud/coal. - On some vehicles (especially diesel scoops), headlights are obscured by machine bucket.
Bolters	Roof	- Better lighting desirable to minimize shadows in cases where the coal/roof parting leaves a rough surface. Shadows inhibit spotting of roof aberrations. - High light level on drill area is desirable but should be without glare.
Loaders, cutters, face drill	Face	- High light levels on face/inby area desirable. - Systems without adjustable headlights are undesirable on face drills because of dim spots which hinder drilling operation.

structure be changed. Some lighting manufacturers have obtained STE-extensions which permit substitution of the new, short, fluorescent luminaires in the canopy area; and this may offer glare advantage.

On machines where top-deck visibility is essential (primarily roof bolters), some companies reported that visibility is improved if "open" mounting brackets are used (Figure 7). These mounts increase light transmission to the deck surface and apparently diminish contrast problems which obscure visibility of objects on the deck surface.

Improvement of face lighting is given high priority by many mine operators. Frequently, additional headlights have been installed on continuous miners. Although increase of light levels is relatively simple, doing so in view of the whiteout problem is most difficult. Many mines have experimented with various headlight configurations, but the results they reported during the study were extremely contradictory. Design optimization criteria (e.g., beam type, lamp orientation, etc.) with relation to typical dust conditions, might result in great improvements in the effectiveness of continuous-miner lighting systems.

Conclusion

Although this paper has concentrated on problem areas, the successes shown by the study should not be overlooked:

(1) Longwall lighting has been implemented with few problems at most mines, and both mine operators and face personnel are reporting many tangible benefits.

(2) No particular maintenance problem is consistently severe on room-and-pillar applications, and many mines reported relatively low maintenance requirements (in mining terms) for this application.

(3) Despite existence of several significant acceptance-related problem areas on room-and-pillar face machines, the majority of face equipment operators appraised their lighting systems favorably overall.

Many of the existing problems can be minimized through more careful specification, design, and implementation of hardware and systems. In some cases, additional research is warranted. The successes to date should serve as a spur to continued evolvement of mine lighting so that the full benefits in personnel safety, comfort, and productivity are realized.

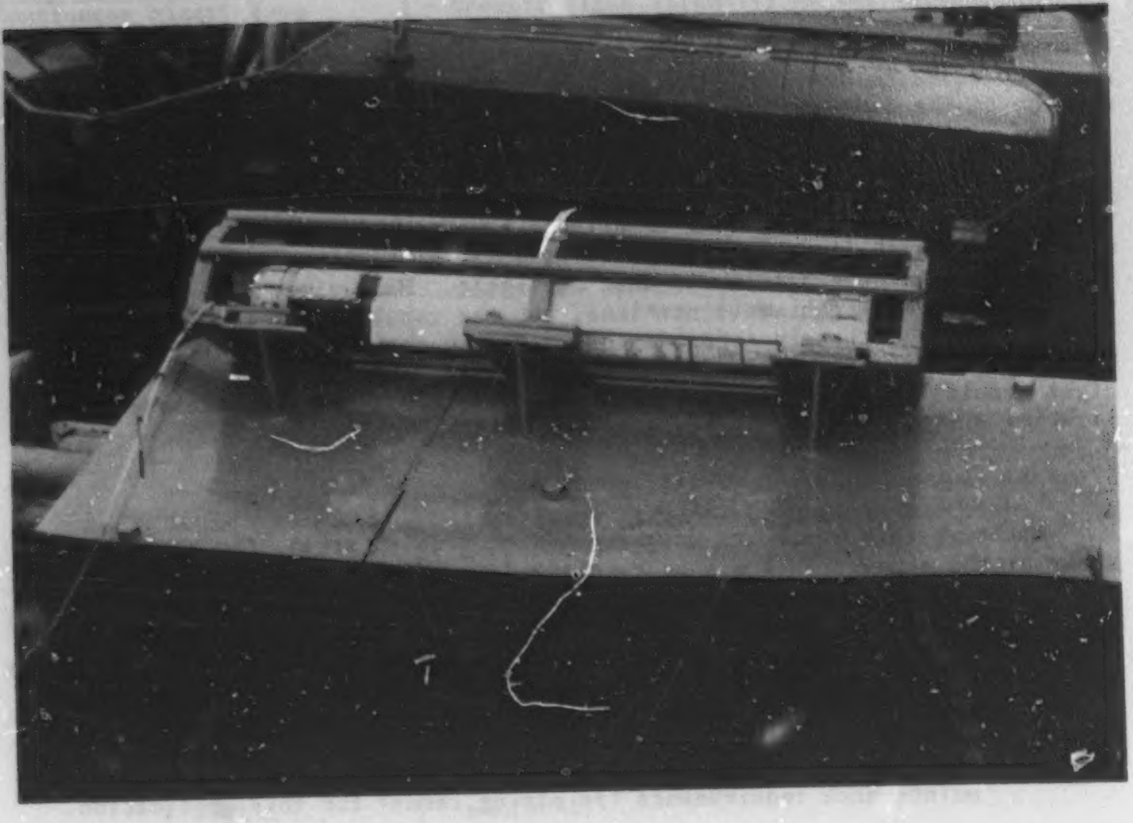


FIGURE 7. - "Open" construction of angle-mount bracket increases light transmission to machine deck surfaces.

TITLE OF PAPER: Efforts to Design Lighting
Systems into Underground
Mining Equipment

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EFFORTS TO DESIGN LIGHTING SYSTEMS INTO UNDERGROUND MINING EQUIPMENT

by

Owen J. Wright[1]

ABSTRACT

The Coal Mine Safety and Health Act of 1969 directed the Secretary of the Interior to propose standards, by December 31, 1970, for permissible illumination of all working places in a coal mine, while persons are working in the area. Such standards were formulated and printed in the Federal Register on December 31, 1970. As a result of written comments, and subsequent consultation meetings, presenting suggestions and objections; these proposed standards were withdrawn.

After consideration of the many comments, suggestions and objections, a revised standard was proposed and published in the Federal Register on October 27, 1971. Again, written comments were invited and received. After extensive investigation, experimentation and testing; a public hearing was held on April 4, 1974.

Following this hearing, on June 28, 1974, a finding of fact was published. It was found that technology existed and stationary and machine mounted systems had been developed, which would produce the required 0.06 foot-lamberts of illumination. However, the difficulty in adapting the systems to the many types of face machines and equipment; and the lack, in the mining industry, of expertise in the illumination engineering field; plus the lack of simple instrumentation, usable underground, still presented a problem in the enforcement of the regulations.

A publication in the Federal Register, on April 1, 1976, served notice the instrumentation and technology was then in existence; and that the regulations would be promulgated on October 1, 1976.

After seven years of investigation, resarch, testing and evaluation, the illumination standards were promulgated, as scheduled, on October 1, 1976. The promulgation allowed a period of eighteen months to bring the working areas of all mines into compliance with 30CFR, Part 75.1719.

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TEXT

Illuminate all working areas of all underground coal mines in the United States. Thousands of unlighted machines were working in hundreds of unlighted areas. Few people, if any, fully realized the magnitude of this gigantic task.

From the inception of the mine illumination program, the need for integration of lighting into machine designs was, of necessity, completely overshadowed by the need to retrofit the many and varied models of machines, then in the working places. As a result, nearly all illumination systems developed were "add-on" features of existing machine designs.

Mining Enforcement and Safety Administration (MESA), later becoming Mine Safety and Health Administration (MSHA), worked, almost entirely, with manufacturers of luminaires and related lighting equipment in the development of lighting systems. Although there was some consultation with mine equipment manufacturers, by these lighting companies, there was little direct involvement of the machine designers and builders.

A few equipment manufacturers and mine operators built dark rooms, simulating mine environment, for use in the design and evaluation of illumination systems. However, most systems are still being developed as "add-ons". It is not practical to redesign a machine, or a series of machine models, just to satisfy lighting requirements. Some manufacturers elect to ignore lighting, and let illumination fixture manufacturers supply the systems for their machines.

The process of incorporating an illumination system into a machine design is not a simple one. A preliminary layout must be made to determine luminaire locations to produce an adequate light output pattern. A prototype chassis, or a mock-up, must then be made, with recesses for protective mounting of light fixtures. The lights must be protected by locations, or shielding must be provided, as a requirement for approval under Part 18 of Title 30, Code of Federal Regulations (30CFR).

Once the overall lighting system layout has thus been tentatively determined, an investigation must be made to determine any interference with the location of other electrical, mechanical or hydraulic components of the machine. Functional or space requirements may limit or preclude the relocation of these other components. In these instances, when interference occurs, it is necessary to relocate the luminaire. Relocation of a light may effect the machine light output pattern to the extent that installation of additional lights may be required, to maintain compliance with the regulations.

In some instances, the relocation of luminaires is not practical. This may require the redesign of the interfering component, to make mounting space available for the luminaire. Deviation from the use of standardized components may result; and if the component is an electrical explosion-proof enclosure, will require an extension of certification or a new certification.

It becomes evident that, although there are obstacles to the integration of lighting in an original machine design, they are not insurmountable. However, inclusion in an existing machine design may cause a prohibitive amount of redesign and additional cost. Thus, the "add-on" type of lighting is still predominantly used.

A mine operator often desires to purchase an unlighted machine and apply an illumination system of his own design, or a design purchased from a luminaire manufacturer. For this reason, the lighting system must be offered as an option on the overall machine design and approval. This, again, encourages the use of "add-on" systems. In other cases, the operator desires a system designed by the machine manufacturer; but specifies a definite make of luminaire. As a result, alternates to the optional system must be offered. Thus MSHA acceptance of each alternate must be obtained, and separate statements of test and evaluation must be provided.

Once a system is designed to produce a satisfactory light output and distribution, the problem of achieving an acceptable glare level rears its ugly head. Acceptable glare is very difficult to define. Comfort and acceptability varies from one individual to another and must be acceptable to the machine operator, his helper and the operators of other machines working in the same area. Glare may be substantially reduced, by placing shields between the light source and the eyes of the observer. However, care must be taken to assure that the shields do not adversely effect the light distribution, to the extent that the system is no longer in compliance with the regulations. In the opinion of the writer, the final resolution of the glare problem must ultimately be the responsibility of the users of the machine, and must be solved while operating in the work area.

Incorporating lighting in the overall machine has a distinct advantage of locating the luminaires so protection is provided against damage due to falling material or rubbing against the mine roof or ribs. "Add-on" fixtures, of necessity, project above or from the sides of the machine, and are vulnerable to damage from these sources. Although it may not be immediately evident, the added protection of an integral lighting system may result in a significant decrease in machine maintenance and repair costs. This is especially true for machines working in low seam heights.

In the case of an "add-on" system, the machine approval seldom includes the lighting electrical circuitry. This necessitates an application, by the machine user or manufacturer, for an extension of approval or a SNAP acceptance, to electrically connect the lights to the machine power. The integral systems are covered by the approval and thus the additional paper work, and delay, is eliminated.

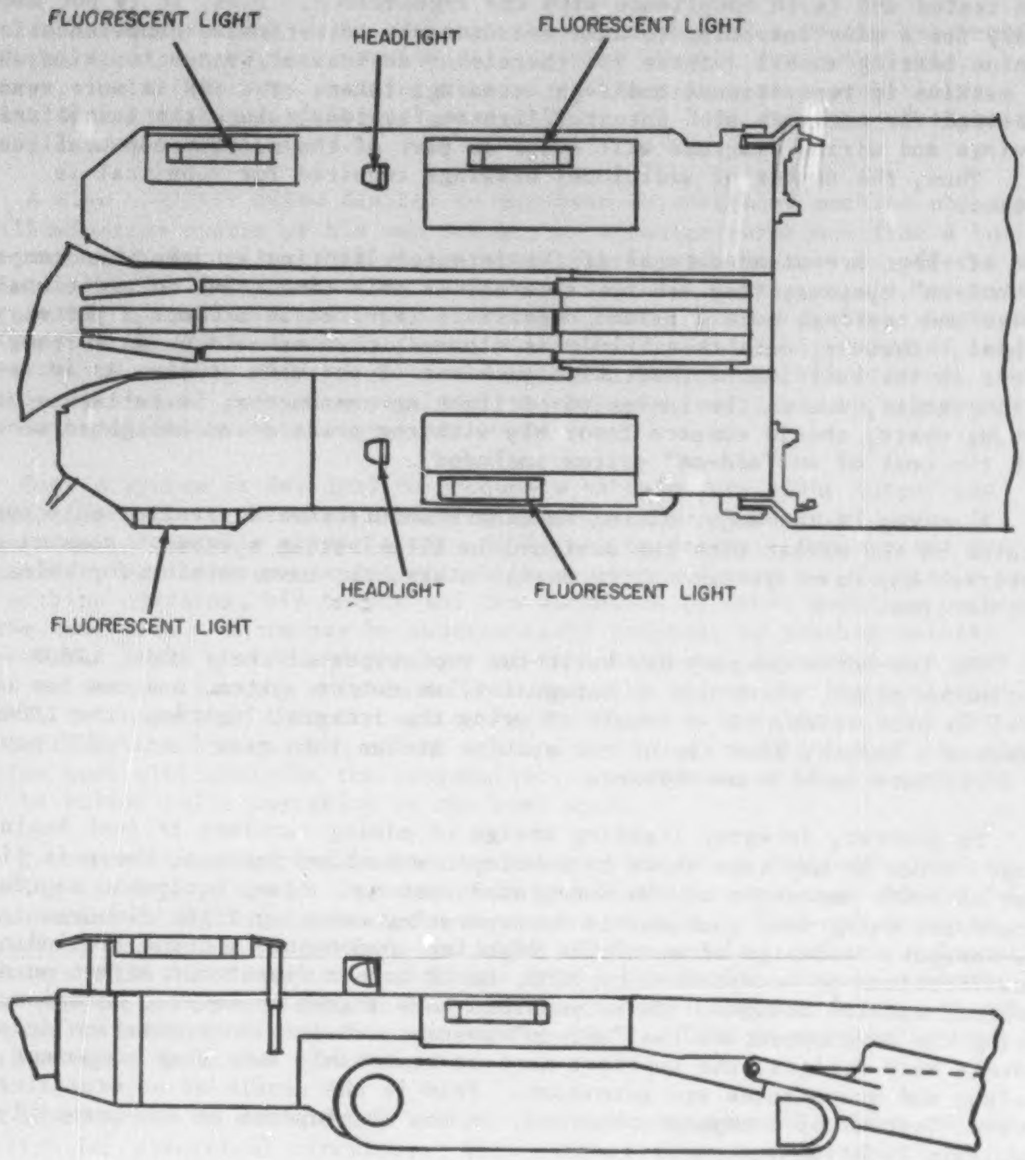
A "Statement of Test and Evaluation" (STE) is an important tool for the mine operator. Possession of an STE is assurance that a lighting system has been tested and is in compliance with the regulations. Thus, it is not necessary for a mine inspector to make measurements to determine compliance for a machine bearing an STE. There is, therefore, no loss of production time while the machine is repositioned and light readings taken. The STE is more readily processed for machines with integral lighting systems, since the installation drawings and wiring diagrams will exist as part of the machine approval package. Thus, the number of additional drawings required for submittal is reduced.

If there are disadvantages of the integral lighting systems when compared to "add-on" systems, they are not apparent at this time. Due to additional design and testing, more time and expense is required to produce a prototype machine. However, once this hurdle is cleared, there should be no further effect in the building of production machines of the same model. An increased selling price, due to the inclusion of lighting components, installation and testing costs; should compare favorably with the price of an unlighted machine with the cost of an "add-on" system included.

A survey of the major mining machinery manufacturers revealed only one machine on the market with the designed-in illumination systems. Some manufacturers may have systems in the design stage, but have nothing for release at this time.

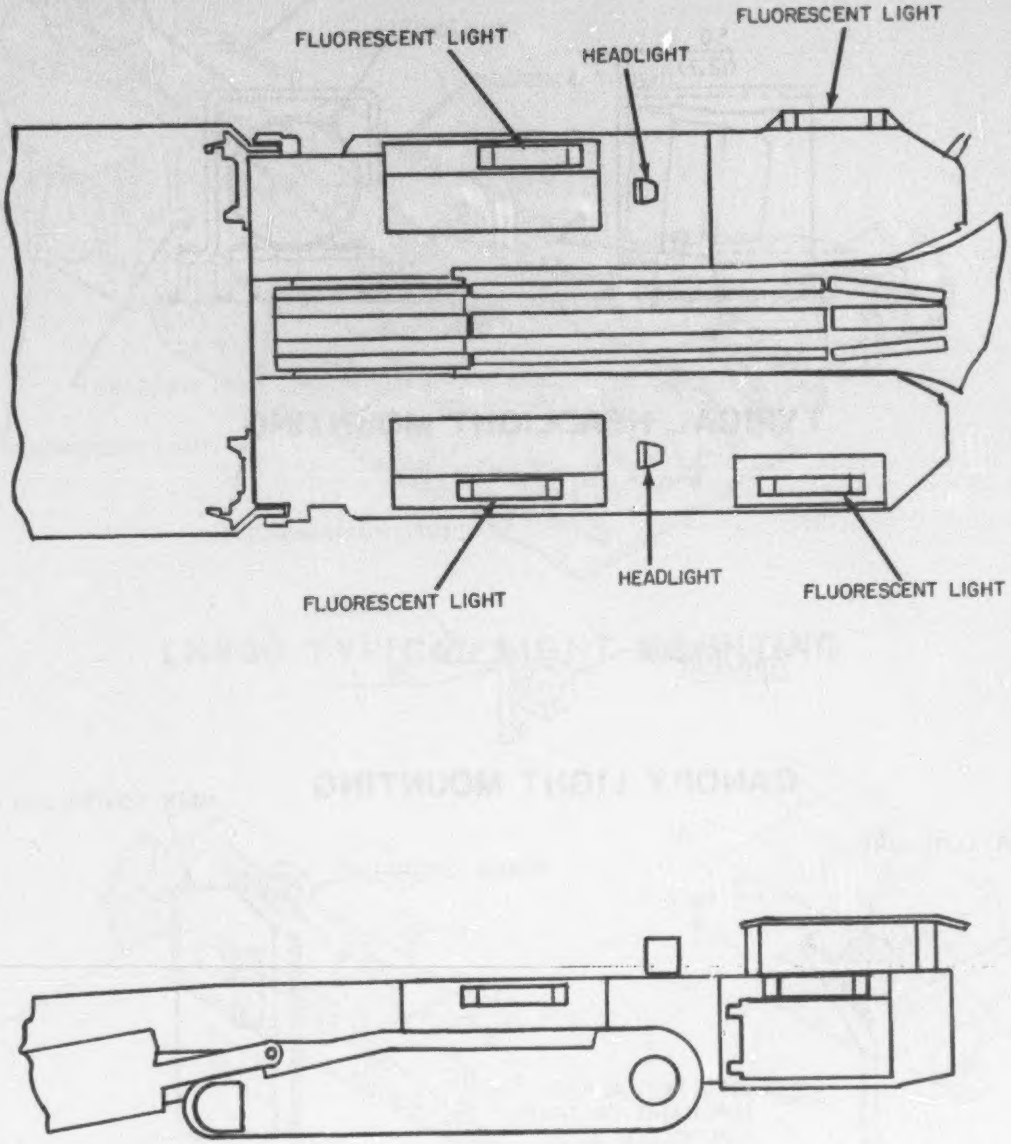
The Lee-Norse Company has built two prototypes of their Model LN800 Continuous Miner, which has an integral illumination system, and now has this model in production. As a result of using the integral lighting, the LN800 presents a smooth, flat top of the machine broken into easy "lift-off" covers, to facilitate machine maintenance.

In general, integral lighting design of mining machines is just beginning. Since it may take years to develop new machine designs, there is little hope of swift emergence of the integrated systems. Also, equipment manufacturers are being very cautious in incorporating existing light fixtures into new designs. Redesign of available lighting components, and the rescinding of certifications or acceptances by MSHA, could have a disastrous effect on newly marketed machine designs. These problems have arisen on several occasions, during the development of the "add-on" systems. Before incorporation into closely knit designs, the builders must be reasonably sure that component designs and acceptances are permanent. This is the result of an expensive lesson, learned by everyone concerned, in the development of the presently available lighting systems.


FLUORESCENT LIGHT
HEADLIGHT
FLUORESCENT LIGHT
HEADLIGHT
FLUORESCENT LIGHT
FLUORESCENT LIGHT

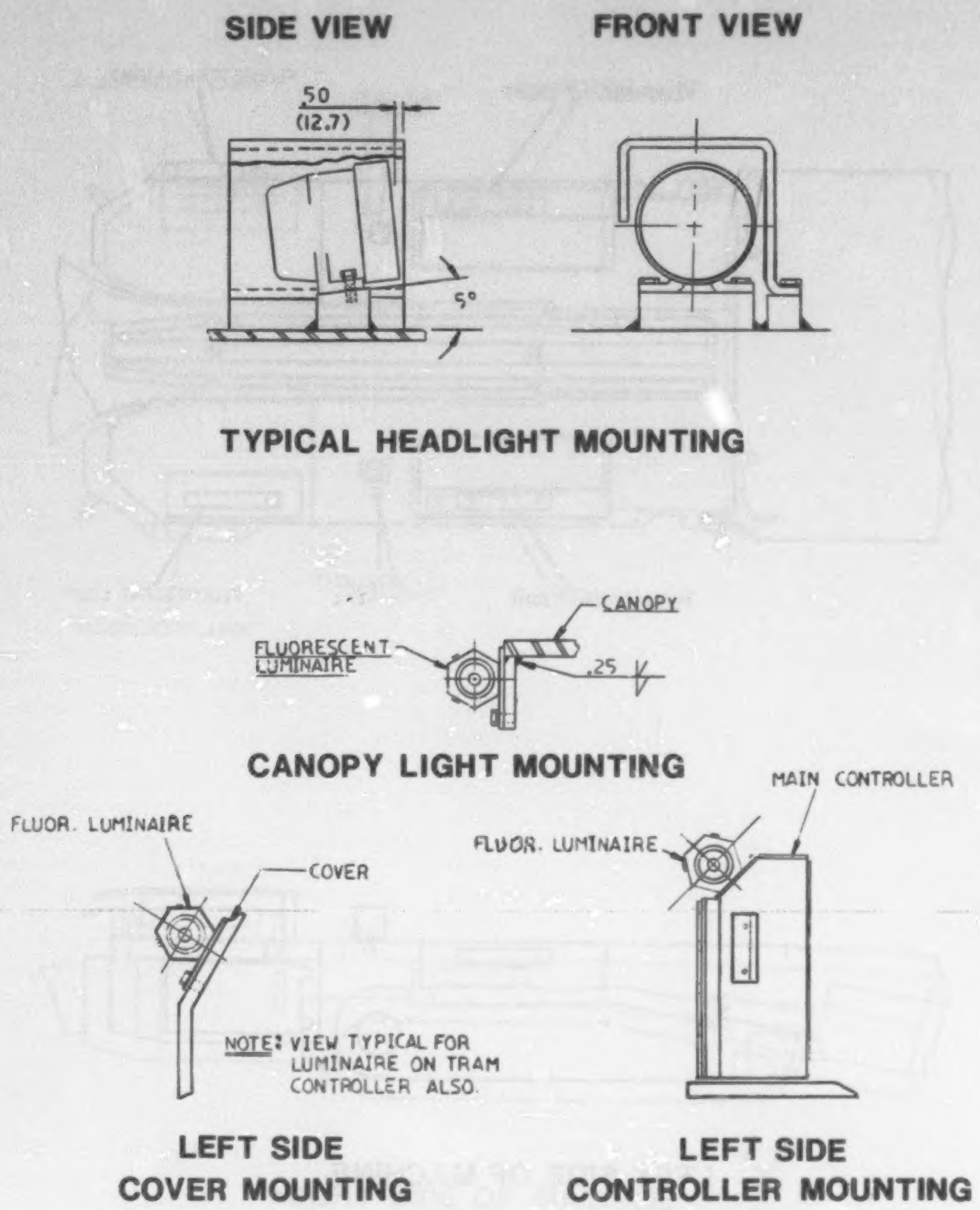
RIGHT SIDE OF MACHINE

Figure 1.


FLUORESCENT LIGHT
HEADLIGHT
FLUORESCENT LIGHT
FLUORESCENT LIGHT
HEADLIGHT
FLUORESCENT LIGHT

LEFT SIDE OF MACHINE

Figure 2.



SIDE VIEW

FRONT VIEW

TYPICAL HEADLIGHT MOUNTING

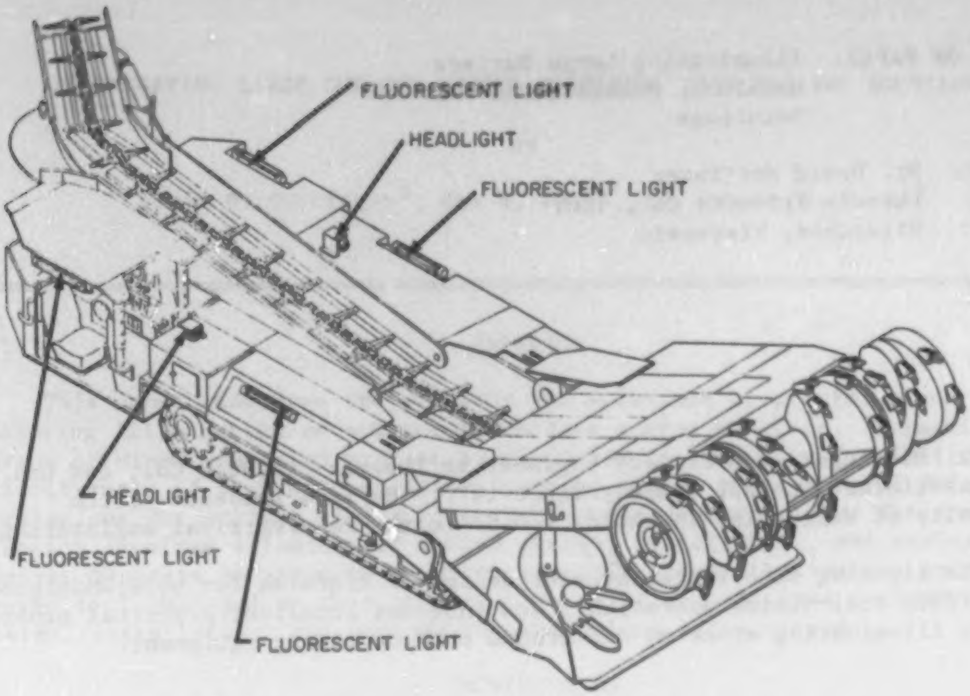
CANOPY LIGHT MOUNTING

LEFT SIDE COVER MOUNTING

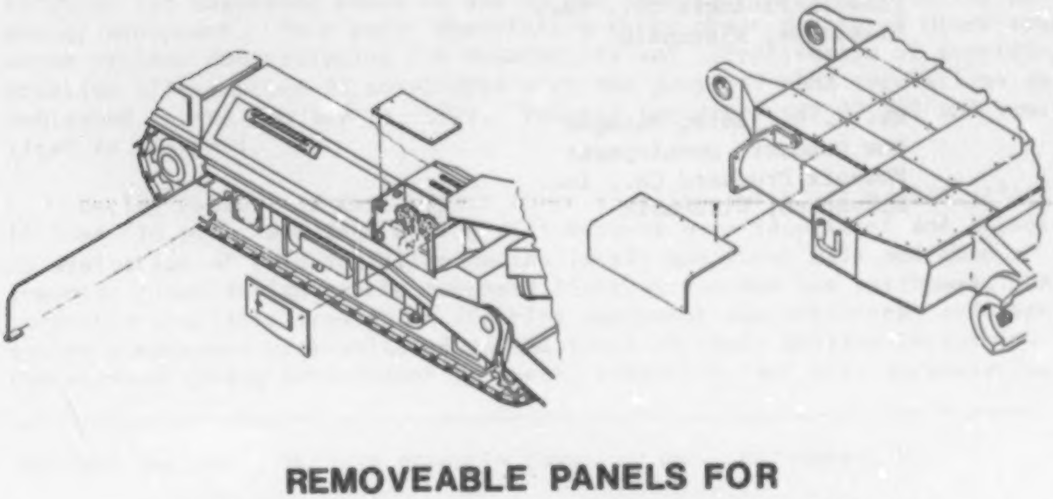
LEFT SIDE CONTROLLER MOUNTING

.50
(12.7)
5°
FLUORESCENT LUMINAIRE
CANOPY
.25
FLUOR. LUMINAIRE
COVER
NOTE: VIEW TYPICAL FOR LUMINAIRE ON TRAM CONTROLLER ALSO.
MAIN CONTROLLER
FLUOR. LUMINAIRE

Figure 3.


FLUORESCENT LIGHT
HEADLIGHT
FLUORESCENT LIGHT
HEADLIGHT
FLUORESCENT LIGHT
FLUORESCENT LIGHT

LN800 TYPICAL LIGHT MOUNTING



REMOVEABLE PANELS FOR MORE EFFICIENT MAINTENANCE

Figure 4.

TITLE OF PAPER: Illuminating Large Surface
Machines, Problems and
Solutions

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His lighting experience includes design of fixtures for both underground and surface coal-mining operations, and includes excellent practical experience in illuminating areas on and around surface mining equipment.

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ILLUMINATING LARGE SURFACE MINING MACHINES, PROBLEMS AND SOLUTIONS

by

David D. Hottinger[1], Ken R. Faux[2], and Rupert O. Yantz[3]

ABSTRACT

This paper addresses the problems and solutions of providing and measuring illumination on and around surface mining machines. Primarily, a Bureau of Mines sponsored project is discussed in which the feasibility and effectiveness of providing dragline lighting to the MSHA proposed Federal Regulations for surface mining illumination was demonstrated. The demonstration involved illumination system design, installation, and evaluation. Special emphasis is given to a unique computer aided illumination system design tool employed on this project. In addition, problems encountered in design, installation, and photometric evaluation are reviewed.

INTRODUCTION

Only a minimum amount of illumination is genarally provided for many types of mobile surface mining equipment. This condition presents a hazard to operating personnel working on and around such equipment. To reduce this hazard MSHA has proposed safety regulations requiring minimum levels of illumination for hazardous zones on and in the immediate area surrounding surface mining equipment. This paper describes a three phase Bureau of Mines sponsored project demonstrating the feasibility and effectiveness of providing dragline illumination in compliance with the proposed MSHA regulations as published in the January 13, 1977, "Federal Register" CFR 77.207 and summarized in Figure 1.

During Phase I of the project three draglines with 9.2 m^3 (12 yd^3), 15.3 m^3 (20 yd^3), and 26.8 m^3 (35 yd^3) buckets were identified and selected. An evaluation of existing illumination levels was first made and then a computer aided design of the proposed lighting systems was performed. Only currently available production lighting equipment was considered and lighting system components were selected on the basis of their ability to survive in the surface mining environment of shock, vibration, and dirt accumulation.

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[2] Manager of Engineering, Phoenix Products Company, Inc., Milwaukee, WI.

[3] Manager - New Product Development, Phoenix Products Company, Inc., Milwaukee, WI.

Average Illumination Intensity in Lux (Footcandles)

LOCATION	Proposed 30CFR	X1.33	* Uniformity Ratio (UR)	METHOD OF MEASUREMENT
1). All areas 6.10m (20 ft.) in all directions from the main frame.	53.80 (5.0)	71.55 (6.65)	10/1	Surface shall be divided into fields having an area not greater than 9.29 sq.m. (100 sq. ft.). The surface of the light sensitive cell shall be held in a horizontal plane approximately 0.76m (30 in.) from surface to be measured. Average illumination intensity for that field shall be the average of five readings; one taken at each of the four corners and one at the center.
2). All work or travel areas beneath the main frame.	53.80 (5.0)	71.55 (6.65)	10/1	
3). Exterior walkways, catwalk and ladders on main frame and boom.	53.80 (5.0)	71.55 (6.65)	10/1	Average illumination intensity shall be average of at least four evenly spaced readings taken at intervals 3.05m (10 ft.) or less. Surface of light sensitive cell shall be horizontal approximately 0.76m (30 in.) from surface to be measured.
4). Area beneath boom from 6.10m (20 ft.) from main frame to furthest point equipment can excavate or discharge material.	10.76 (1.0)	14.31 (1.33)	10.1	Average illumination intensity shall be average of at least four evenly spaced readings at intervals of 3.05m (10 ft.) or less along the center line of the boom. The boom shall be placed over level terrain and the first reading shall be taken 6.10m (20 ft.) ahead of the main frame.

* Uniformity ratio shall be calculated as the average to minimum illumination intensity.

FIGURE 1. - MSHA recommended lighting levels.

Lamp selection was based on efficacy and suitability to each situation. Computer calculated lighting levels for each of the three lighting systems included a 33 percent lamp lumen depreciation factor in meeting the proposed regulations.

In Phase II of the project each of the lighting systems was installed. After installation a photometric survey for each of the three lighting systems was performed and evaluated in accordance with the methods outlined in the proposed regulations.

Phase III of the project included a second photometric survey for each of the three lighting systems after a three month period of lighting system operation. Lighting system hardware failures were logged and evaluated. Reactions of the workers to the lighting system were also recorded at this time.

The project represented by this paper demonstrated the capability of providing illumination levels meeting or exceeding the proposed MSHA regulations for dragline mounted lighting systems using currently available technology and hardware.

This paper presents only a summary with typical examples of the data and results obtained. Presented first is a discussion of the tasks accomplished in each phase of the project with results and special problems encountered highlighted. Observations made during the project and comments pertinent to those observations are presented next. Conclusions and recommendations resulting from the entire effort are discussed in the final portion of this paper.

In the interest of condensing this paper and keeping it informative, data for only the Marion 184-M dragline are included as representative of all three draglines involved in the demonstration. However, unique features, problems, and solutions for the other two draglines are discussed.

A complete report of the project conducted is available through the Bureau of Mines.

DESCRIPTION OF DRAGLINES

As the initial task of Phase I, the following three draglines were selected for the illumination demonstration project.

A. Marion - Type 184-M Dragline
Operated By: Cobb Coal Company
Location: Saragossa Surface Mine
Carbon Hill, Alabama

The Marion Type 184-M dragline is a crawler type machine with a main frame measuring approximately 5.8 m (19 ft) wide by 10.1 m (33 ft) long by

6.1 m (20 ft) high. The machine is constructed with a 36.6 m (120 ft) long boom and a 9.2 m^3 (12 yd^3) bucket. Accessory electric power is supplied by an auxiliary diesel driven 37.5 KVA 60 Hertz generator. The generator had an excess capacity of approximately 8 KVA available for additional lighting at a nominal 440 volts. Photographs of this dragline are included in Figure 2. This, the smallest of the three draglines, was selected primarily as the most detrimental shock and vibration environment for lighting equipment.

B. Page - Model 7-32 Dragline
Operated By: Westmoreland Coal Company
Location: Westmoreland's No. 8 Surface Mine
Leivasy, West Virginia

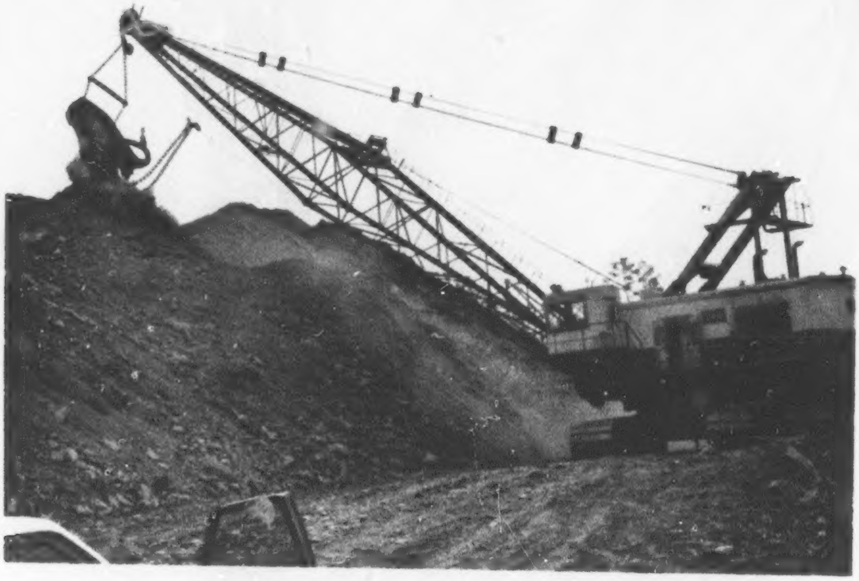
The Page Model 7-32 dragline is a walking type machine powered by diesel motors. The main frame measures approximately 9.5 m (31 ft) wide by 19.4 m (63.5 ft) long by 9.1 m (30 ft) high. The machine is constructed with a 61 m (200 ft) long boom and a 15.3 m^3 (20 yd^3) bucket. Power for the original lighting equipment was supplied by a 15KW D.C. generator driven by one of the main diesel motors. The light output from fixtures connected to this generator was very unstable and diminished significantly as the diesel motor RPM dropped under heavy loading. A photograph of this dragline is shown in Figure 3.

C. Marion - Type 7800 Dragline
Operated By: Bankhead Mining Company
Location: Parrish Surface Mine
Route 2
Parrish, Alabama

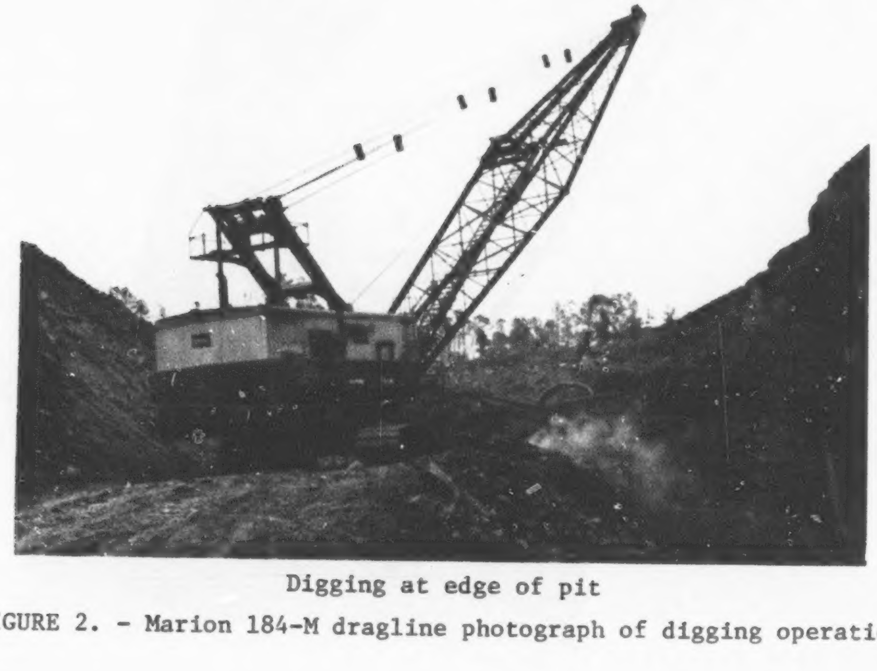
The Marion Type 7800 dragline owned by Bankhead Mining Company is a walking type machine with a main frame measuring approximately 16.2 m (53 ft) wide by 20.1 m (66 ft) long by 10.7 m (35 ft) high. The dragline is constructed with a 79.3 m (260 ft) long boom and a 26.8 m^3 (35 yd^3) bucket. The machine was driven by electric motors with power supplied by a 7200 volt A.C. trailing cable. A step down transformer supplied 480 volt power for operation of the lighting system. Photographs of the machine are shown in Figure 4.

INITIAL EQUIPMENT AND PHOTOMETRIC SURVEY

As the second task of Phase I the existing lighting system installed on each machine was inspected to determine type, location, state of repair, design, and mounting. External photometric measurements were made in accordance with the proposed regulations summarized in Figure 1. Light level readings were taken around the main frame, beneath the main frame (in work or travel areas), on the main frame and boom walkways and beneath the boom. Photometric layouts were then plotted for each of the three machines to determine areas of compliance, or severity of non-compliance. Some areas of the draglines were so poorly lighted that readings indicated light levels below 0.11 Lux (0.01 ft-c), the limit of sensitivity of the measuring



Dumping at max. spoil pile height



Digging at edge of pit

FIGURE 2. - Marion 184-M dragline photograph of digging operation.

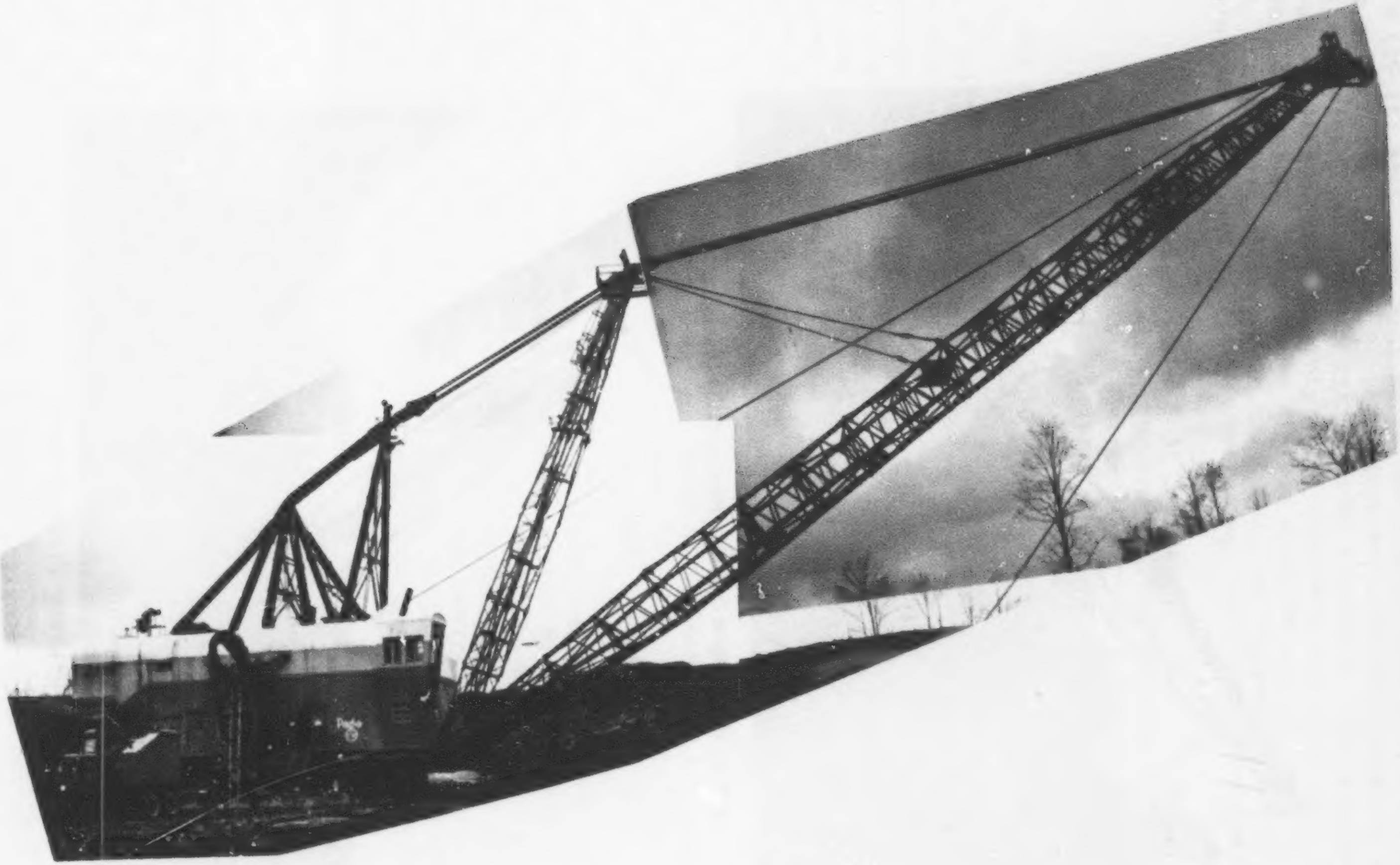


FIGURE 3. - Page 7-32 dragline composite photograph.

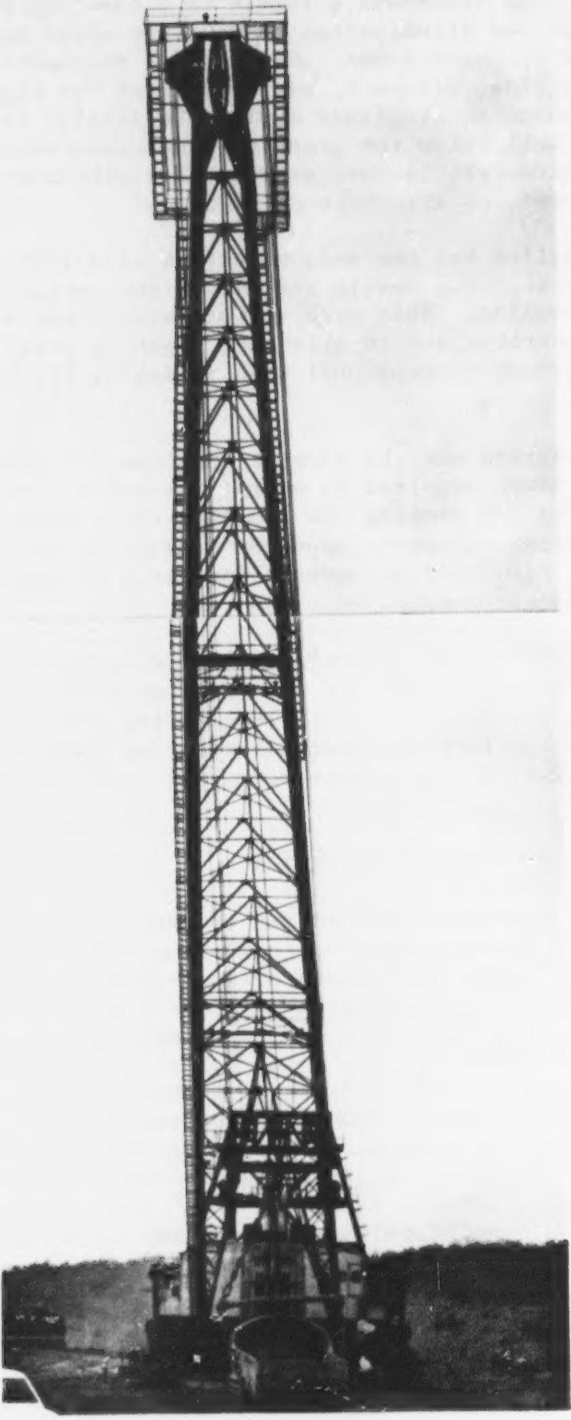


FIGURE 4. - Marion 7800 dragline composite photograph.

instrumentation. This low light level was a result of either failure to relamp fixtures or to provide for illumination of specific areas including walkways and the area around the main frame. The initial photometric survey of the Marion Type 184-M dragline, Figure 5, was typical of the lighting condition existing around the three draglines during the initial investigation. Lighting levels were well below the proposed MSHA requirements. Figure 5 is also typical of the photometric layouts prepared for all other areas, in which illumination was measured, on all three machines.

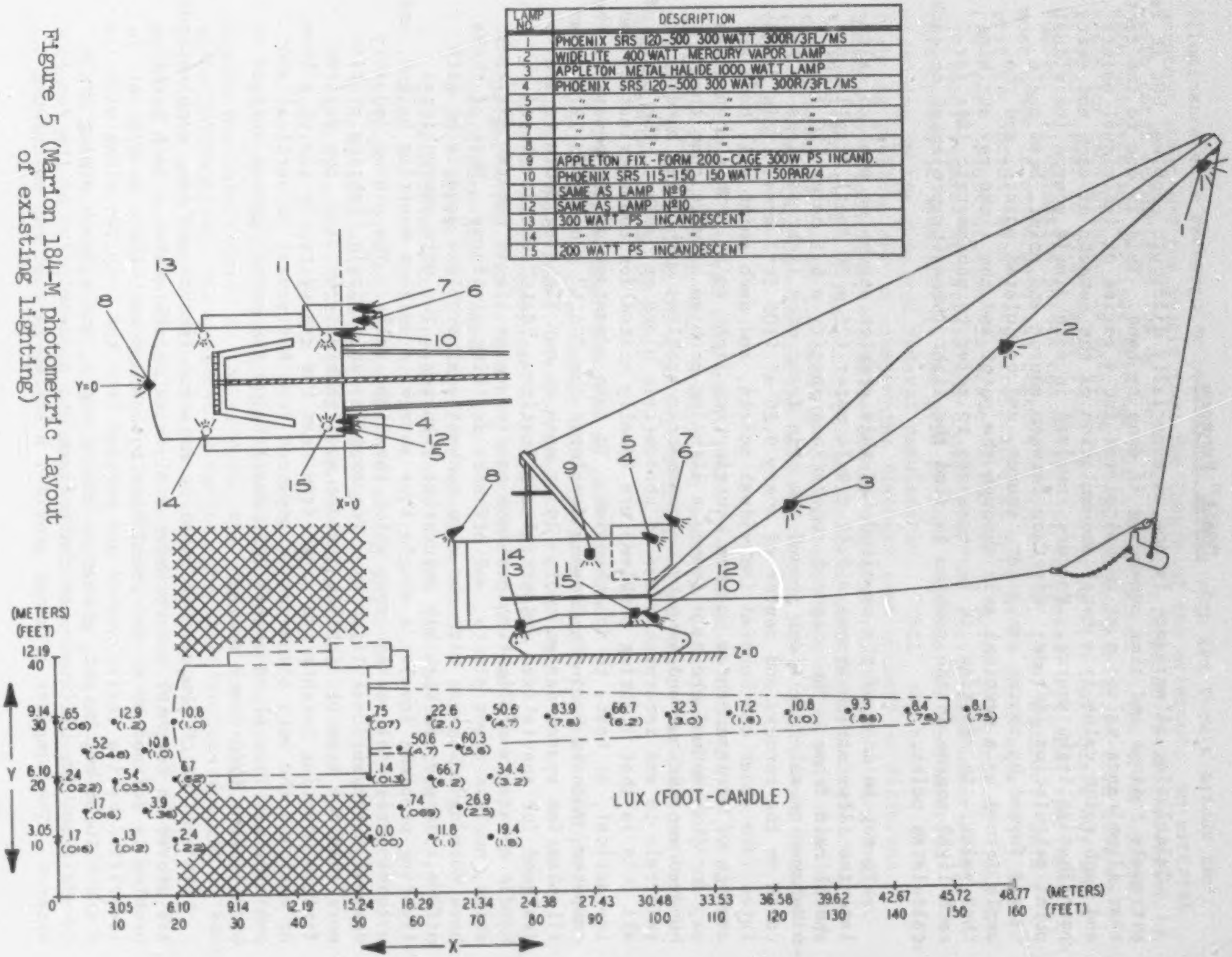
The Page Model 7-32 dragline had the unique feature of a 15KW D.C. generator coupled to the main diesel. The result was that light output varied significantly with machine loading. This machine was retrofitted with a 25KW A.C. diesel powered motor generator set to eliminate lighting level variations and to allow the use of efficient conventional high intensity discharge lighting equipment.

The Marion Type 7800 dragline was the largest dragline included in the study and the only one with power supplied by a trailing cable. No illumination was originally provided for tending the trailing cable during walking operations at night. Individual operators reported difficulty in "keeping track" of the trailing cable resulting in several incidents of severing the cable during night walking operations.

As part of the initial photometric survey, available engineering drawings were reviewed and visual observations made of all three machines to locate areas requiring illumination and identify suitable mounting positions. Particular attention was given to selecting potential mounting locations which were structurally sound, accessible for maintenance, and free of light blocking obstructions.

LIGHTING SYSTEM DESIGN

Until recently lighting equipment was applied to draglines primarily for productive purposes in an unsystematic manner. A minimum number of lighting fixtures were used only at key areas for safety or individual task performance. The potential benefit of improved personnel safety and productive capability to be realized by an integrated systematic application of lighting equipment to the individual dragline and the total operational function was not fully appreciated or evaluated. The objective of this project was to illuminate three draglines in accordance with the proposed MSHA requirements in order for the Bureau of Mines to evaluate improved personnel safety. A key element used in the lighting system design phase was a computer program designated "CALL" for Computer Aided Lighting Layout. "CALL" was developed by Phoenix Products Company, Inc., specifically to assist the lighting engineer in designing lighting systems for unique applications such as draglines.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Z=0
Y=0
X=0
LUX (FOOT-CANDLE)
(METERS)
(FEET)
12.19 40
9.14 30
6.10 20
3.05 10
0
3.05 10
6.10 20
9.14 30
12.19 40
15.24 50
18.29 60
21.34 70
24.38 80
27.43 90
30.48 100
33.53 110
36.58 120
39.62 130
42.67 140
45.72 150
48.77 160
Y
X
.65 (.06)
12.9 (1.2)
10.8 (1.0)
.52 (.048)
10.8 (1.0)
.24 (.022)
.54 (.055)
6.7 (.62)
.17 (.016)
3.9 (.36)
.17 (.016)
.13 (.012)
2.4 (.22)
.75 (.07)
22.6 (2.1)
50.6 (4.7)
83.9 (7.8)
66.7 (6.2)
32.3 (3.0)
17.2 (1.6)
10.8 (1.0)
9.3 (.86)
8.4 (.78)
8.1 (.75)
50.6 (4.7)
60.3 (5.6)
.14 (.013)
66.7 (6.2)
34.4 (3.2)
.74 (.069)
26.9 (2.5)
0.0 (.00)
11.8 (1.1)
19.4 (1.8)

LAMP NO.	DESCRIPTION
1	PHOENIX SRS 120-500 300 WATT 300R/3FL/MS
2	WIDELITE 400 WATT MERCURY VAPOR LAMP
3	APPLETON METAL HALIDE 1000 WATT LAMP
4	PHOENIX SRS 120-500 300 WATT 300R/3FL/MS
5	" " " "
6	" " " "
7	" " " "
8	" " " "
9	APPLETON FIX.-FORM 200-CAGE 300W PS INCAND.
10	PHOENIX SRS 115-150 150 WATT 150PAR/4
11	SAME AS LAMP Nº9
12	SAME AS LAMP Nº10
13	300 WATT PS INCANDESCENT
14	" " "
15	200 WATT PS INCANDESCENT

Figure 5 (Marion 184-M photometric layout of existing lighting)

FIGURE 5. - Marion 184-M photometric layout of existing lighting.

"CALL" Program

Calculating illuminance is not an especially difficult problem, but it is extremely tedious and time consuming if done by hand. This is due to the fact that illuminance values must be calculated for a series of individual points and each point value is a total accumulation of the outputs of each and every contributing light source. Factors involved in each single source individual point calculation include: distance between source and point, beam angle (angle formed by source aim point, source, and calculated point), and the angle formed by a vertical axis through the point and the light ray striking that point. In addition, it is necessary to refer to photometric data for each light source in the problem to find the light intensity projected on each calculated point.

To get an idea of the magnitude of this problem assume we want to calculate the illumination around a 7.62 x 9.14 meter (25 x 30 foot) dragline or shovel main frame. The proposed regulations specify a 6.1 meter (20 foot) wide area on all four sides around the main frame with light readings to be taken on the corners and center of every 9.26 m^2 (100 ft^2) area. This translates into about one hundred individual points, and each point will have an average of at least three sources contributing light to it. This then gives us, for just around the máin frame, a lighting problem of more than three hundred repetitious and lengthy trigonometric problems with three hundred referrals to and interpretations of photometric plots or tables. The point of all this is that lighting problems are ideally suited for computerization and impractical, at best, to do otherwise. To take advantage of the powers of the computer, Phoenix Products Company developed the "CALL" program in 1974 as an illumination system design tool. In as much as our lighting products are designed for specialized industrial applications, "CALL" was developed to handle a variety of lighting problems as diverse as liquid natural gas tank ships, nuclear power plants, and offshore drilling platforms. Most of these have nothing in common with the more conventional problems associated with office, roadway, or high bay industrial lighting. The more conventional lighting problems involve a single type source, a uniform mounting height, and a level horizontal surface upon which the light falls. The mining industry demands unconventional lighting. For example, in a single lighting problem more than one type of lighting fixture must generally be used, the desired fixture mounting heights can range from near the ground to the tip of a boom or mast and the work plane can be anywhere from horizontal to vertical and run anywhere from 60.96 meters (200 feet) below the normal ground surface to 60.96 meters (200 feet) above.

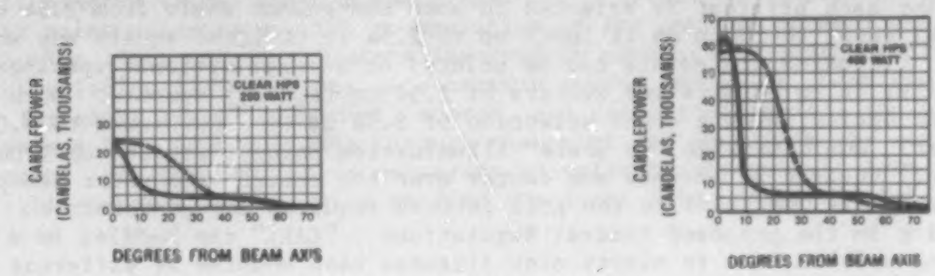
In the "CALL" program, photometric data for fixture and lamp combinations are stored in computer memory under a discrete serial number. Each lighting problem is defined by an X-Y coordinate system and each light source is identified by its serial number and entered into the computer along with its X and Y location, height, elevation aiming angle, and azimuth aiming angle. In addition, identification of the project and a description of the run is entered. The computer printout provides a scaled plot of the calculated illuminance on a rectangular coordinate system with the Y-axis across the printout sheet and the X-axis down the length of the printout. An asterisk (with total accumulated lux or footcandles) is printed at the intersection of each ordinate and abscissa selected for a calculation by the print option. Scale for each printout is selected to some convenient scale from 2.54 cm (1 inch) equal to 30.48 cm (1 foot) up to 2.54 cm (1 inch) equals any whole number. Illumination points can be printed on several optional spacings. The most dense is on corners and centers of 2.54 cm (1 inch) squares. Such a printout option, with a scale selection of 2.54 cm (1 inch) equal to 3.048 m (10 feet), would provide "to scale" illumination point printouts on 3.048 m (10 foot) squares at corners and center over the entire area under study. This option is identical to the grid pattern required for photometric measuring in the proposed Federal Regulations. "CALL" can handle, in a single lighting problem, one to ninety-nine fixtures each mounted at different heights, X-Y locations, elevation aiming angles, and azimuth aiming angles. In addition, twenty different types of fixtures with dissimilar photometric characteristics can be included in a single problem. It is this flexibility that allowed "CALL" to handle the unconventional lighting problems demanded by this project.

The "CALL" program uses candlepower distribution curves, such as those shown in Figure 6, for each fixture and sums the light contributed by each fixture at every point in a predetermined grid pattern. The data entered in the computer are as follows:

LP# - Serial number assigned to each fixture.
Type - Computer code number of candlepower curve for each fixture.
Loc X - The X coordinate location of the fixture.
Loc Y - The Y coordinate location of the fixture.
Height - The fixture mounting distance above a predetermined X-Y coordinate grid plane.
Elev - Elevation is the fixture aiming elevation angle above the perpendicular with zero being taken as the fixture pointing straight down.
Azimuth - Azimuth is the fixture aiming angle of rotation in a counter clockwise direction relative to the X-Y plane. Zero azimuth angle indicates the center of the fixture beam pattern is aimed in the positive X-direction.

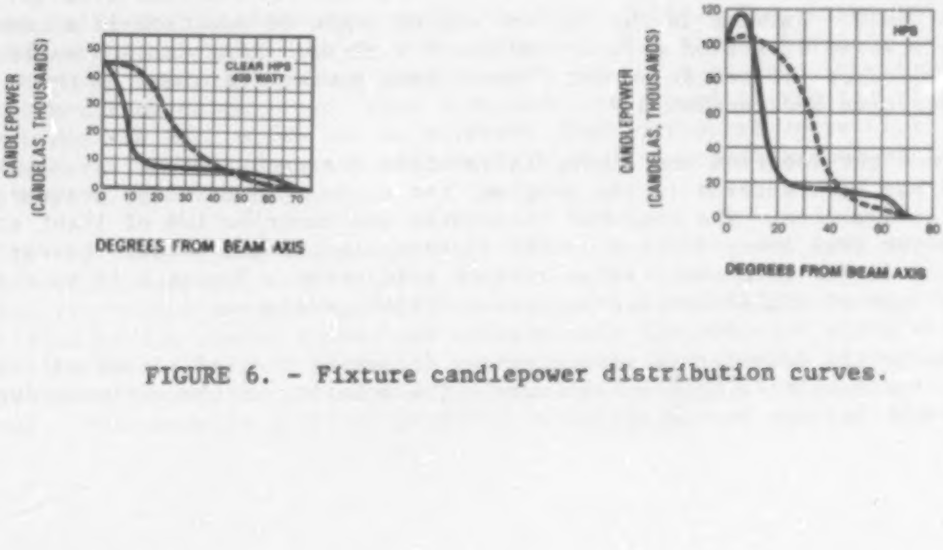
Once the location and aiming information for each fixture in a lighting system has been entered in the program, the engineer enters the desired grid plane information. The computer calculates the contribution of light at each grid point from every fixture in the lighting system and prints the corresponding lux or footcandle value at each grid point. Figure 8 is an example of the type of scaled computer printout "CALL" generates.

While the computer is very accurate in making the individual calculations, the result is only an estimate. The accuracy of the estimate depends on several factors including:



MODEL SRS-EB-400 FIXTURE
WITH 250 WATT HIGH
PRESSURE SODIUM LAMP

MODEL SRS-EA-400 FIXTURE
WITH 400 WATT HIGH
PRESSURE SODIUM LAMP



MODEL SRS-EB-400 FIXTURE
WITH 400 WATT HIGH
PRESSURE SODIUM LAMP

MODEL SRS-EA-1000 FIXTURE
WITH 1000 WATT HIGH
PRESSURE SODIUM LAMP

FIGURE 6. - Fixture candlepower distribution curves.

Lumen Output

Initial lamp lumen output varies approximately ±20 percent between individual production lamps from the nominal rated values presented in the manufacturers literature. All candlepower distribution curves are corrected to the nominal rated values presented in the manufacturers literature.

Lamp lumen depreciation over life is significant. The 1000 watt HPS lamp has an initial rated lumen output of 140,000 and a 126,000 lumen output at 50 percent rated life or 12,000 hours at 10 hours operation per start. This represents a 10 percent reduction in light output. If the lamp is started more frequently, the lumen output will depreciate faster.

Lamp lumen output changes with variations in line voltage. A 120 volt incandescent lamp operated at 116 volts will experience a 10 percent decrease in light output. A 400 watt high pressure sodium lamp operating with a constant wattage autotransformer will experience a 10 percent decrease in light output with a 10 percent decrease in line voltage.

Fixture lumen output will vary with the accumulation of dirt on the lens or reflector. Dirt depreciation factors are tied to the specific application and frequency of maintenance.

Candlepower Curve Output

Manufacturing variation in reflector shape and position can easily cause a 10 percent reduction in candlepower contributing to a point in a grid system.

Lamp location variations can result in either a reduction in the candlepower contributing to a point in a grid system or a shift in the whole beam pattern.

Secondary reflections of light off machine structures can result in errors. Reflections off the walls of a light colored machine house can be a source of such an error.

Geometrical Relations

Fixture beam pattern blockage by the mechanical components of the machine can result in drastic reductions in the candlepower contributing to a point in a grid system. The "CALL" program makes no allowance for light level losses due to beam pattern blockage by mechanical machine components. Machine obstructions that result in light level calculation errors include the boom steel matrix structure, support structures for the feet on walking draglines, rails for maintenance cranes extending from the rear of the machine house, and various walkways. During installation care must be taken to avoid light blocking obstructions.

Perpendicularity of the ground plane to the vertical center line of the machine house will significantly effect fixture aiming and light level measurements.

Equipment Selection and Application

Floodlighting was used wherever possible for area lighting. By design, spill from these lights was used to provide lighting for the various walkways. This approach minimized the total number of individual fixtures required for each dragline lighting system. High Intensity Discharge--"H.I.D."--lamps, especially High Pressure Sodium, were used whenever practical because of the high efficacy and long life of this lamp.

The incandescent lamp produces light by heating a tungsten filament. Since the filament is heated to very high temperatures it can easily be broken. Special lamps can be made more resistant to mechanical stress, but are still limited in lamp life to between 2,000 and 6,000 hours. The high pressure sodium lamp consists of a translucent ceramic arc tube with an electrode sealed in each end. Light is produced by a high temperature arc stream between the two electrodes. This structure is very strong and able to resist very high shock and vibration stresses. A lamp life of up to 24,000 hours makes this lamp very desirable for use on surface mining equipment.

Illumination levels under the main frame of the machine were computed at ground level instead of 0.76 m (30 in.) above the ground. Because of the very restricted mounting height in areas beneath the main frame, lighting fixtures located in this area are very close to the surface being illuminated. Measuring light levels 0.76 m (30 in.) above the ground--half the distance between the fixture and the ground in one case--presents a distortion of the actual illumination contributing to the seeing conditions for the individual miner.

The access walkways on the main frame of each dragline were illuminated by spill from the lighting fixtures used to illuminate the area around the main frame. Light for the ladders on the walls of the main frame and on the gantries came from the lighting fixtures used to illuminate the area around the main frame or the roof. Since the lighting fixtures are aimed nearly parallel with ladders or located behind them, the present light level measurement requirements could result in unrealistic readings even though a ladder is well lighted for functional use.

Boom walkways were illuminated by floodlights mounted on the main frame and/or on the main frame gantry. This lighting system design approach was used to reduce the total number of the lighting fixtures mounted on the boom. However, walkways near the tip of each boom required boom mounted lighting fixtures to provide acceptable illumination levels. Since all the lighting fixtures mounted on the boom were mounted close to the walkway for ease of maintenance, light levels were calculated at the illuminated surface rather than 0.76 m (30 in.) above it.

During the initial equipment and photometric survey, each dragline operator requested additional light be directed at the point sheave of the boom to improve the operator function of judging the closeness of the bucket and cable knot to the point sheave. A 250 watt high pressure sodium lighting fixture was mounted on the boom of each dragline and directed towards the hoist rope line near the point sheave. This lighting fixture was only a partial solution to the problem. The additional light did illuminate the bucket as intended. However, the boom structure prevented the operator from seeing the point sheave from his control station. The improved lighting did make it easier for the operator to estimate the closeness of the bucket knot to the point sheave.

Lighting Level Calculations

After investigating each dragline for the application of lighting fixtures, specific areas and equipment were identified and evaluated in the "CALL" program. The results of the study for each dragline were presented in summary drawings giving the location and a complete description of each lighting fixture in the lighting system. An outline of each dragline or dragline section was superimposed on the appropriate computer profile to indicate the relative location and estimated light levels. Since the lighting problems of all three machines are similar, this paper presents only the data and results for the 184-M dragline as being typical. Only exceptions due to unique features of the other two draglines are discussed.

Marion Type 184-M Dragline

Figure 7 presents plan and elevation views of the location and aiming of each lighting fixture. Figures 8 through 12 present the "CALL" program lighting profiles for the various areas included in the study. Lighting fixtures 16 and 17 shown in Figure 7 were selected to evaluate incandescent lamp life in the shock and vibration environment presented by the boom.

The boom walkway on this dragline runs along the top surface of the boom leaving no possibility for lighting the tip of the boom from gantry mounted floodlights. Any overhead fixture mounting structure would be subject to damage by the boom support cable. Fixtures 16 and 17 shown in Figure 7 were mounted just above the boom walkway hand rail. A potential solution to this problem, not evaluated in this study, would be to illuminate the grating that forms the walkway from below.

Page - Model 7-32 Dragline

The unique feature of this machine was that the tailpiece only cleared the ground by approximately 0.61 m (2.0 ft) as shown in the photograph Figure 13. Providing illumination in this area was not considered photometrically or mechanically practical.

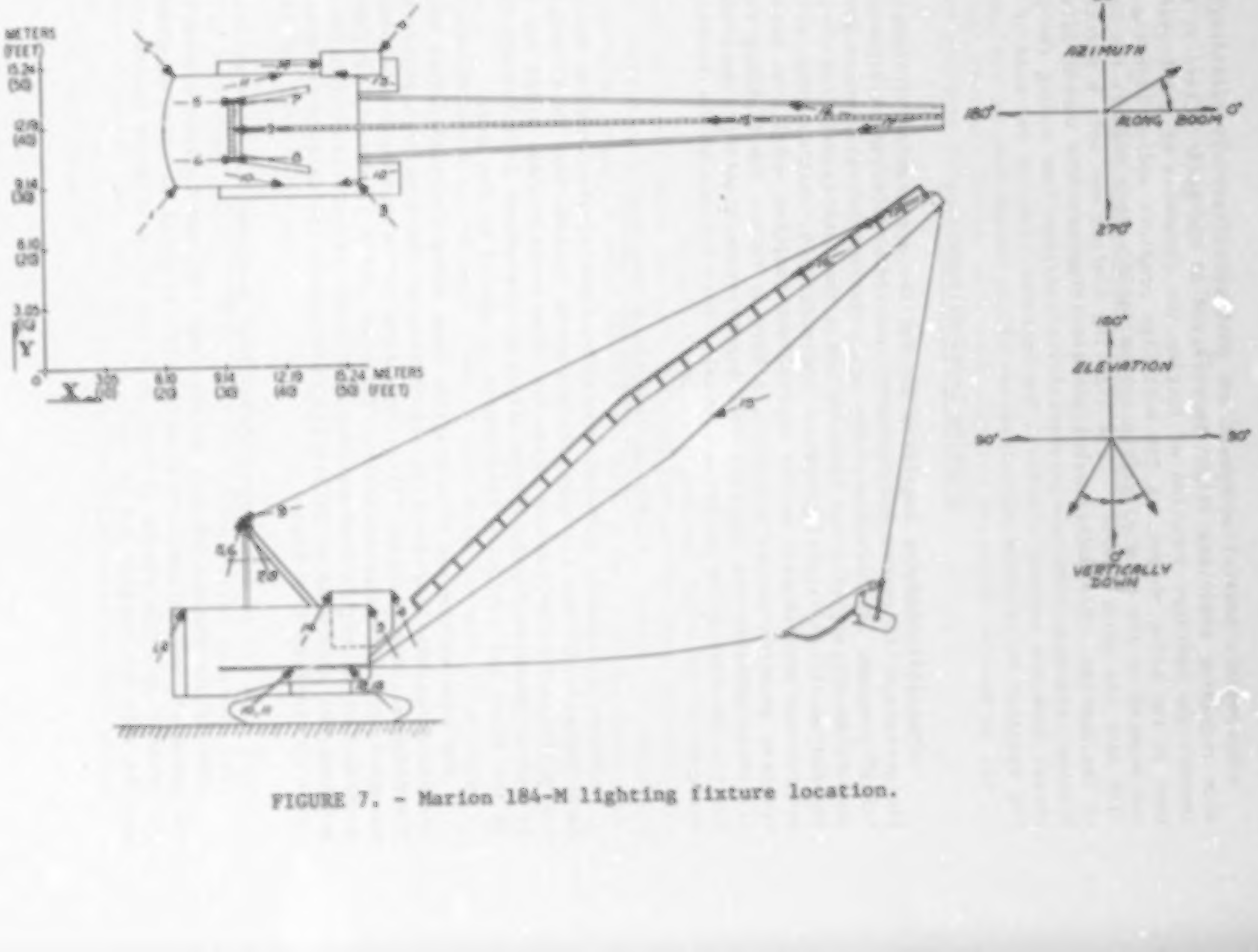

METERS
(FEET)
15.24
(50)
12.19
(40)
9.14
(30)
6.10
(20)
3.05
(10)
Y
0
X
3.05
(10)
6.10
(20)
9.14
(30)
12.19
(40)
15.24 METERS
(50) (FEET)
90°
AZIMUTH
180°
ALONG BOOM
0°
270°
180°
ELEVATION
90°
90°
0°
VERTICALLY
DOWN

FIGURE 7. - Marion 184-M lighting fixture location.

```
MARION 184-M DRAGLINE LIGHTING PROFILE                        ILLUMINATION LEVEL UNDER MAIN FRAME
ILLUMINATION VALUES REPRESENT CUMULATIVE RAW FOOTCANDLES----NO MAINTENANCE FACTOR WAS USED

LP #  G/W   X-LOC    Y-LOC     HEIGHT   ELEV   AZIMTH  LP-FACTOR  IV  R-VALUE      LAMP DESCRIPTION

  1   107   40.00    20.00     8.80    50.00  168.00    1.00     0   10.49    H175RDXFL39-22 MERCURY VAPOR
  2   107   40.00    38.50     8.80    50.00  192.00    1.00     0   10.49       SAME AS LAMP ABOVE
  3   107   49.00    20.00     8.80    45.00   12.00    1.00     0    8.80       SAME AS LAMP ABOVE
  4   107   49.00    38.50     8.80    45.00  348.00    1.00     0    8.80       SAME AS LAMP ABOVE
                                  SCALE IN BOTH DIRECTIONS (1 INCH = 5.0 FT.)
```

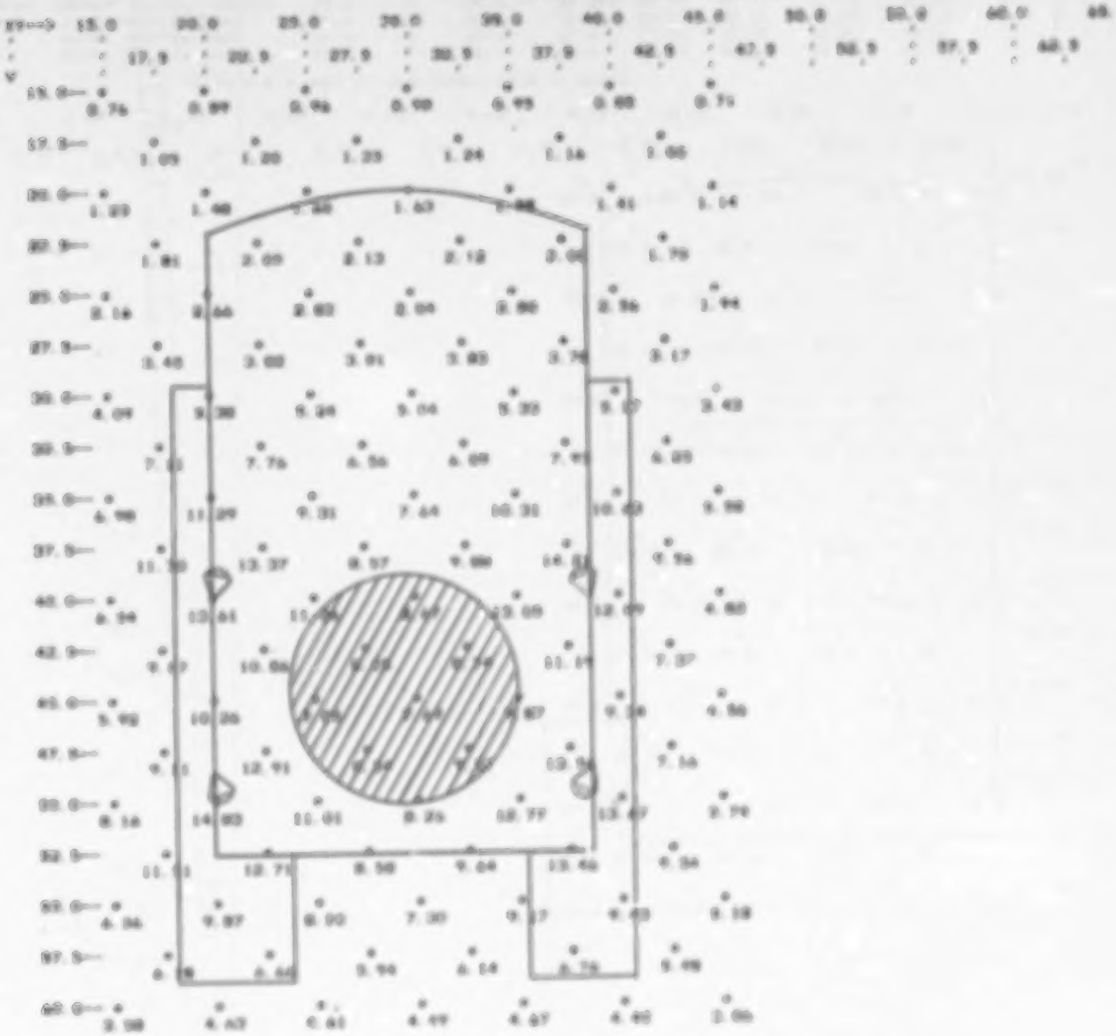


FIGURE 8. - Marion 184-M dragline lighting profile under main frame.

```
MARION 184-M DRAGLINE LIGHTING PROFILE                    ILLUMINATION LEVEL ON ROOF OF MAIN FRAME
ILLUMINATION VALUES REPRESENT CUMULATIVE RAW FOOTCANDLES----NO MAINTENANCE FACTOR WAS USED
LIGHTING FIXTURES ---SRS175MB(10016)

                                                                            LAMP DESCRIPTION
LP #   S/N    X-LOC    Y-LOC    HEIGHT   ELEV   AZIMTH  LP-FACTOR  IV  R-VALUE

 1     107    32.00    34.50    16.00   15.00  180.00     1.00     0    4.29    H175RDXFL39-22 MERCURY VAPOR
 2     :07    32.00    24.50    16.00   15.00  180.00     1.00     0    4.29       SAME AS LAMP ABOVE
 3     107    32.00    34.50    16.00   25.00    0.00     1.00     0    7.46       SAME AS LAMP ABOVE
 4     107    32.00    24.50    16.00   25.00    0.00     1.00     0    7.46       SAME AS LAMP ABOVE
                                         SCALE IN BOTH DIRECTIONS (1 INCH = 5.0 FT.)
```

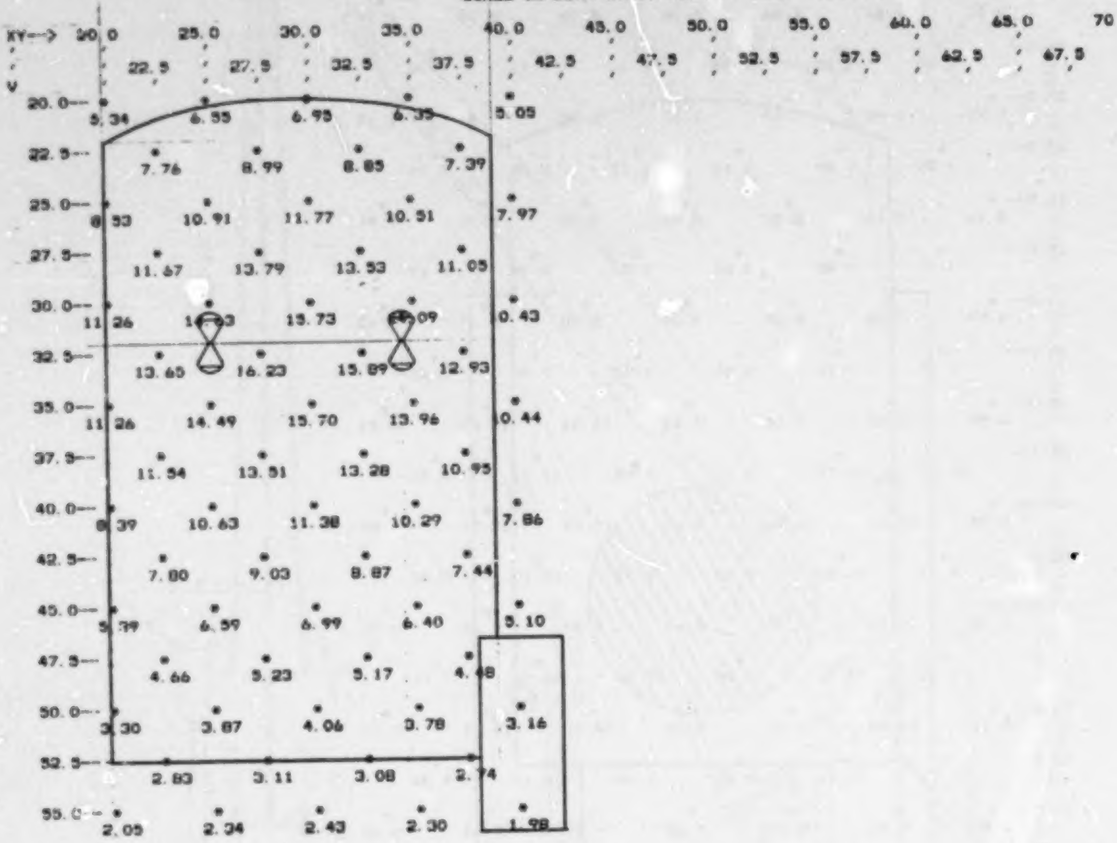


FIGURE 9. - Marion 184-M dragline lighting profile roof level of main frame.

READEX
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```
MARION 184-M DRAGLINE LIGHTING PROFILE                    ILLUMINATION LEVEL ALONG BOOM WALKWAY
ILLUMINATION VALUES REPRESENT CUMULATIVE RAW FOOTCANDLES----NO MAINTENANCE FACTOR WAS USED
INCANDESCENT FIXTURES ARE SRS-115-15C

LP #   S/N    X-LOC     Y-LOC     HEIGHT    ELEV    AZIMTH  LP-FACTOR  IV  R-VALUE     LAMP DESCRIPTION

  3   1207     8.00     30.00      8.00    10.00   230.00     1.00     0     1.41   SRS-EA-400,COATED HPS LAMP
  4   1207    13.00     52.00      8.00    16.00   130.00     1.00     0     2.29      SAME AS LAMP ABOVE
  7   1201     0.00     40.00     34.00    62.00     0.00     1.00     0    63.94   SRS-EA-1000 CLEAR HPS
 16      3    90.00     42.00      3.00    76.00   350.00     1.00     0    12.03   150 PAR/3FL-120 INC
 17      3   105.00     38.00      3.00    76.00    10.00     1.00     0    12.03      SAME AS LAMP ABOVE

                                  SCALE IN BOTH DIRECTIONS (1 INCH =10.0 FT.)
```

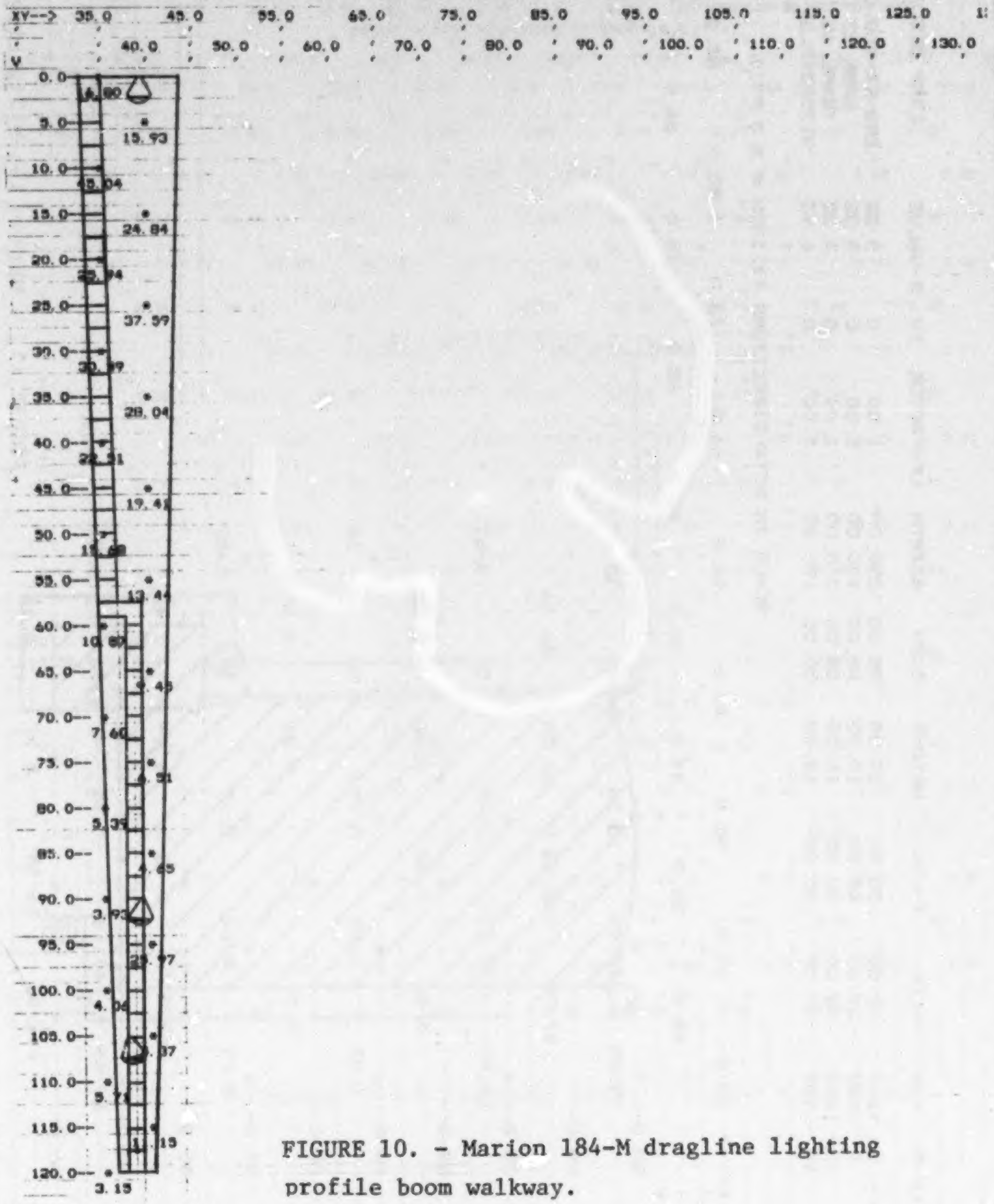

FIGURE 10. - Marion 184-M dragline lighting profile boom walkway.

```
MARION 184-M DRAGLINE LIGHTING PROFILE                    ILLUMINATION LEVEL ALONG MAINFRAME WALKWAY
ILLUMINATION VALUES REPRESENT CUMULATIVE RAW FOOTCANDLES----NO MAINTENANCE FACTOR WAS USED

LP #   S/N    X-LOC    Y-LOC    HEIGHT    ELEV   AZIMTH  LP-FACTOR  IV  R-VALUE      LAMP DESCRIPTION

  1   1207    22.00    30.00    10.00    28.00   230.00    1.00     0    5.32    SRS-EA-400,COATED HPS LAMP
  2   1207    22.00    48.00    10.00    28.00   130.00    1.00     0    5.32      SAME AS LAMP ABOVE
  3   1207    52.00    30.00    10.00    28.00   310.00    1.00     0    5.32      SAME AS LAMP ABOVE
 14    107    47.00    50.00    12.00    30.00   180.00    1.00     0    6.93    H175RDXFL39-22 MERCURY VAPOR

                                        SCALE IN BOTH DIRECTIONS (1 INCH = 8.0 FT.)
```

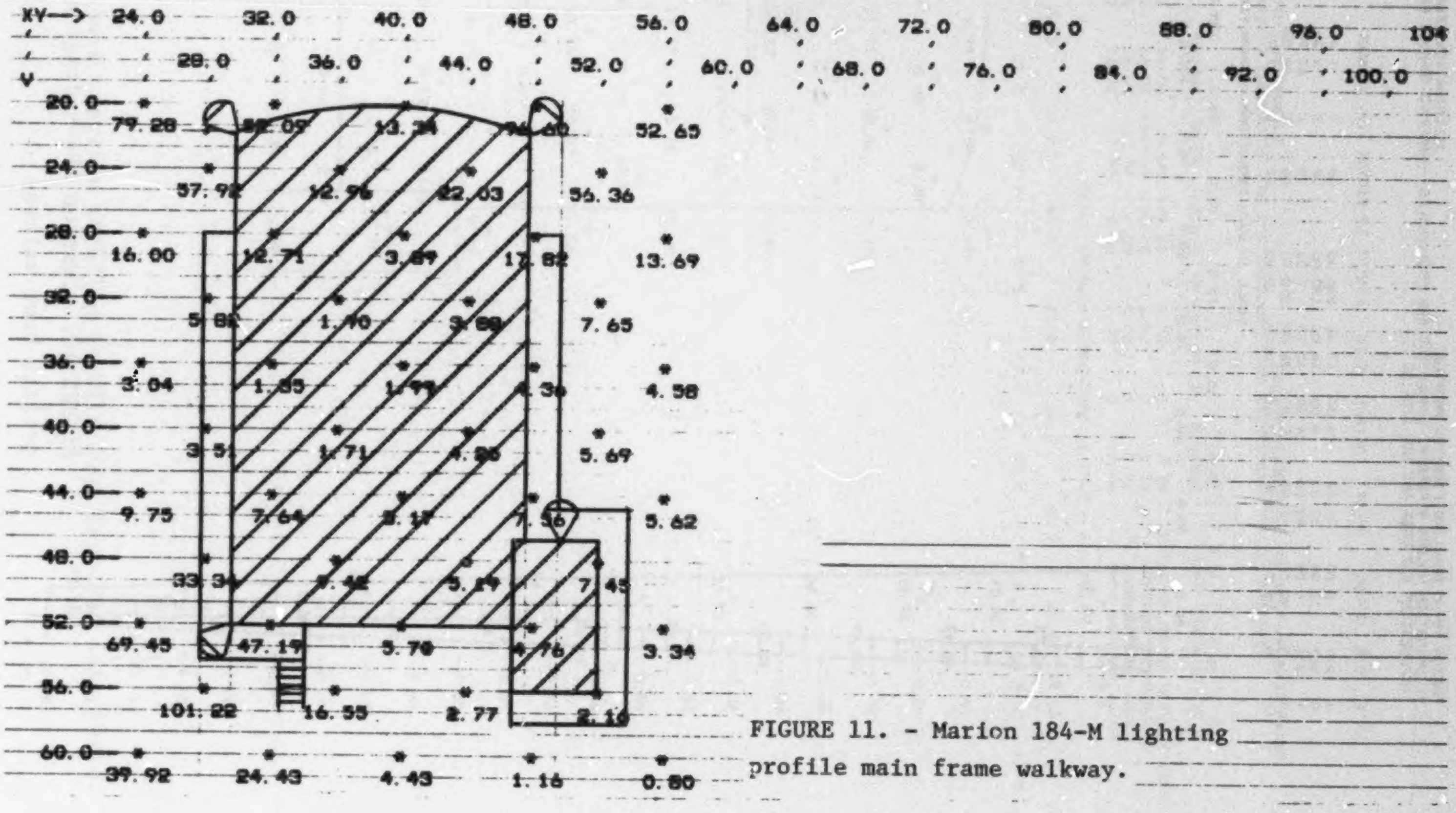

FIGURE 11. - Marion 184-M lighting profile main frame walkway.

```
MARION 184-M DRAGLINE LIGHTING PROFILE                    ILLUMINATION LEVEL AROUND MAINFRAME
ILLUMINATION VALUES REPRESENT CUMULATIVE RAW FOOTCANDLES----NO MAINTENANCE FACTOR WAS USED

LP #  S/N   X-LOC   Y-LOC   HEIGHT  ELEV   AZIMTH  LP-FACTOR  IV  R-VALUE     LAMP DESCRIPTION

  1   1207  22.00   30.00   20.00   28.00  230.00    1.00     0   10.63   SRB-EA-400,COATED HPS LAMP
  2   1207  22.00   48.00   20.00   28.00  130.00    1.00     0   10.63      SAME AS LAMP ABOVE
  3   1207  52.00   30.00   20.00   28.00  300.00    1.00     0   10.63      SAME AS LAMP ABOVE
  4   1207  56.00   51.00   22.00   22.00   50.00    1.00     0    8.89      SAME AS LAMP ABOVE
 14    107  47.00   50.00   22.00   30.00  180.00    1.00     0   12.70   H175RDXFL39-22 MERCURY VAPOR
                                   SCALE IN BOTH DIRECTIONS (1 INCH = 8.0 FT.)

XY-->  0.0     8.0     16.0    24.0    32.0    40.0    48.0    56.0    64.0    72.0    80.0    88.0
           4.0     12.0    20.0    28.0    36.0    44.0    52.0    60.0    68.0    76.0    84.0
Y
  0.0-- *
         1.39    2.84    4.62    5.53    4.94    4.62    5.16    5.35    4.23    2.48    1.43
  4.0--
             2.69    3.89    9.23    8.49    6.59    6.98    9.12    8.58    4.69    2.30
  8.0-- *
         2.21    5.09   10.86   15.52   10.95    8.74   12.48   15.04    9.38    4.06    1.93
 12.0--
             3.72    9.71   19.59   21.78   12.10   13.33   22.90   17.12    8.04    3.06
 16.0-- *
         2.36    6.32   16.53   29.20   19.40   13.07   25.22   28.00   13.58    5.00    2.21
 20.0--
             3.70   10.33   23.21   27.82   24.15   19.15   29.41   19.85    7.84    3.17
 24.0-- *
         2.38    5.02   12.06   21.93   25.18   17.65   17.33   21.18    9.92    4.31    2.11
 28.0--
             3.04    6.03   10.69   12.79    9.40   10.10   13.01    9.85    5.33    2.71
 32.0-- *
         2.14    3.75    6.27    8.29    7.80    6.89    8.05    8.30    5.81    3.41    1.96
 36.0--
             2.76    4.61    6.64    6.95    6.05    6.16    6.96    6.33    4.26    2.55
 40.0-- *
         2.14    3.72    6.11    7.84    7.06    5.07    6.68    7.07    5.48    3.43    1.99
 44.0--
             3.15    6.01   10.04   10.79    7.87    7.89   28.69    7.70    4.93    2.81
 48.0-- *
         2.53    5.27   12.26   18.40   13.04    8.82   10.46   11.77    8.27    4.39    2.24
 52.0--
             4.04   11.11   23.30   25.80   12.19   11.81   16.95   16.44    7.71    3.51
 56.0-- *
         2.76    7.53   18.02   29.95   17.95   11.41   17.32   25.33   15.61    5.93    2.60
 60.0--
             4.19   10.90   21.95   22.94   11.70   12.78   25.74   23.26   11.09    3.93
 64.0-- *
         2.46    6.06   12.30   17.22   11.23    9.28   16.78   23.61   14.98    6.15    2.53
 68.0--
             3.00    6.54   10.35    9.00    7.14    8.75   16.11   15.10    8.51    3.39
 72.0-- *
         1.71    3.13    5.09    5.91    5.32    5.48    7.75   11.25    8.50    4.08    2.01
 76.0--
             1.76    2.74    3.62    3.76    3.78    4.42    5.83    6.00    4.04    2.23
 80.0-- *
         1.08    1.84    2.23    2.53    2.61    2.86    3.47    3.87    3.29    2.21    1.35
```

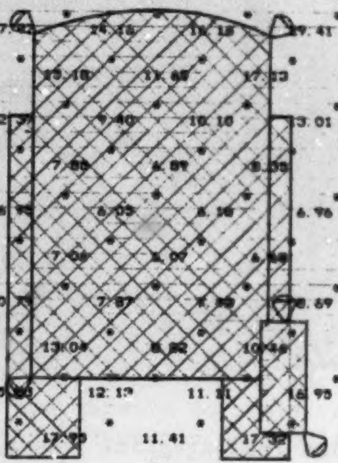

FIGURE 12. - Marion 184-M lighting profile around main frame.

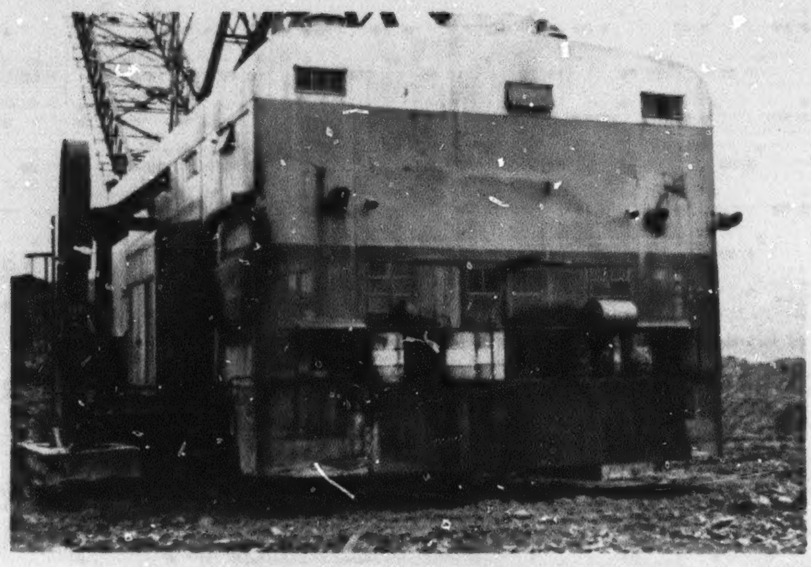

FIGURE 13. - Page 7-32 dragline photograph of ground clearance.

Marion - Type 7800 Dragline

Draglines usually operate very close to the edge of the pit. As the bucket is brought up debris is left along the pit edge. This debris is occasionally struck by the tailpiece as it swings. To avoid lighting fixture damage under the broad tailpiece of the Marion 7800 dragline, the lighting fixtures were placed closer to the tub. These fixtures were aimed at the tub to avoid blinding someone walking toward the machine. This light fixture placement resulted in a low illumination level under the rear of the main frame, but provided reasonable seeing conditions.

LIGHTING SYSTEM INSTALLATION AND INITIAL EVALUATION

The first task of Phase II was the installation of lighting equipment on each dragline. This was accomplished by mine personnel or contractors in accordance with the appropriate lighting system design plan discussed in the preceeding section of this report. All lighting fixtures were mounted and located as close as possible to the intended position determined by the "CALL" program studies. Individual location changes and/or discrepancies are discussed under the appropriate dragline heading in this section of the report. All lighting fixtures were aimed using the coordinates indicated in the "CALL" program studies.

As the second task of Phase II, photometric data were taken as the lighting installations on each dragline were completed. Photometric data were taken at 0.76 m (30 in.) above ground level around the main frame of the dragline by swinging the machine into a desired position relative to a prepared grid matrix of 3.1 m (10 ft) squares. Photometric readings were taken at the corners and centers of each square. These data were presented on photometric layouts for ease of comparison to the initial calculated data for each dragline. The initial average footcandle and uniformity ratios were calculated from the measurements taken and were presented on photometric layouts for each dragline. This paper presents the details for only the 184-M dragline as being typical of all three. Unique features or problems for the other two draglines are discussed.

Marion - Type 184-M Dragline

The results of the photometric measurements taken on the Marion Type 184-M dragline are presented in Figures 14 and 15. A comparison of the design lighting levels under the main frame shown in Figure 8 and the initial measured lighting levels shown in Figure 14 indicates actual levels much lower than originally estimated. This is a result of light blockage by the crawlers and the contour of the underside of the main frame. As the main frame swings, the position of the two lighting fixtures under the main frame relative to the crawlers changes and so does the resulting light blockage by the crawlers. Thus the ground level illumination under the rear of the main frame is variable depending on machine position. The actual light level provided under the rear of the main frame was considered adequate for the functional tasks to be

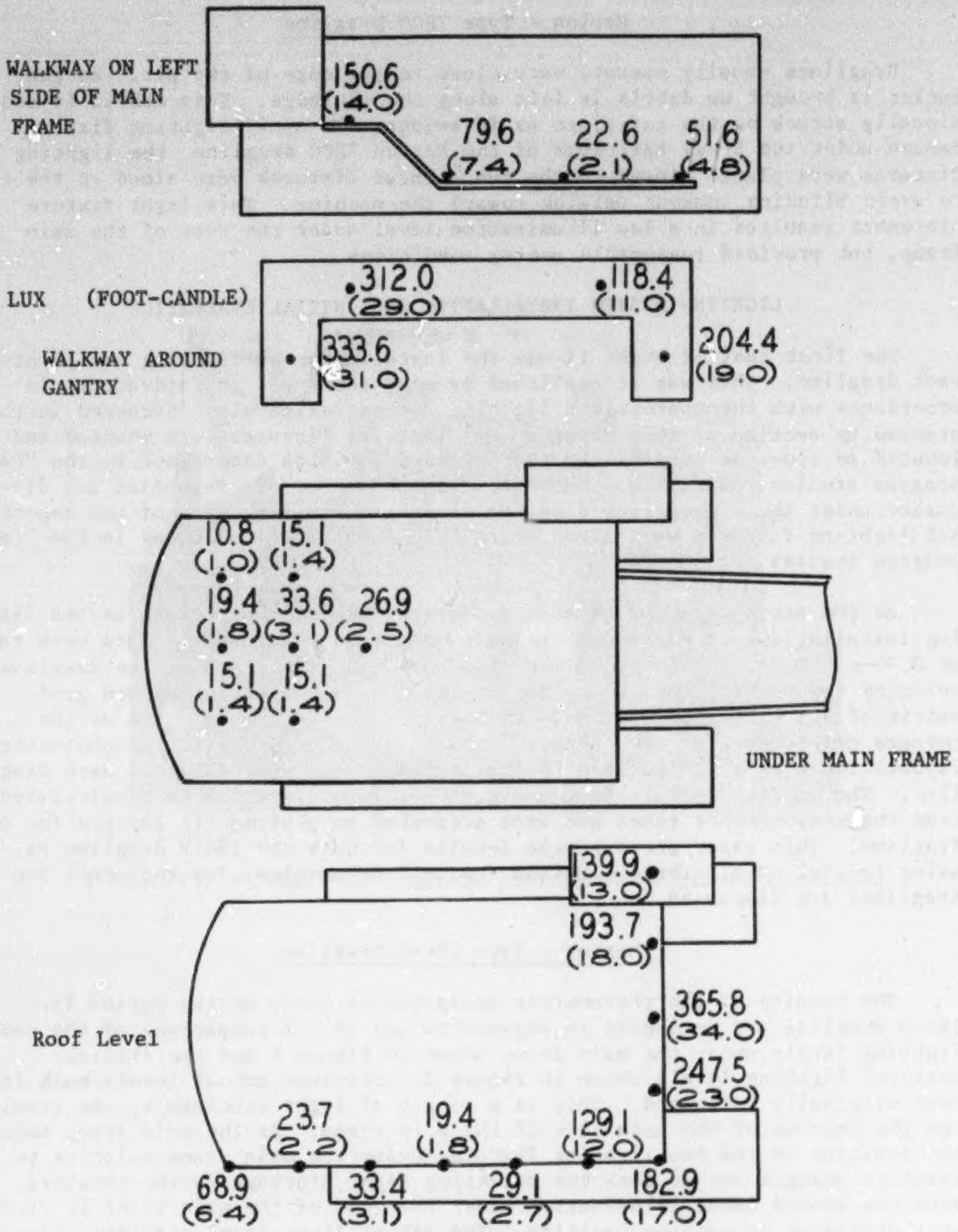
WALKWAY ON LEFT SIDE OF MAIN FRAME
150.6 (14.0)
79.6 (7.4)
22.6 (2.1)
51.6 (4.8)
LUX (FOOT-CANDLE)
312.0 (29.0)
118.4 (11.0)
WALKWAY AROUND GANTRY
333.6 (31.0)
204.4 (19.0)
10.8 (1.0)
15.1 (1.4)
19.4 (1.8)
33.6 (3.1)
26.9 (2.5)
15.1 (1.4)
15.1 (1.4)
UNDER MAIN FRAME
139.9 (13.0)
193.7 (18.0)
365.8 (34.0)
247.5 (23.0)
Roof Level
23.7 (2.2)
19.4 (1.8)
129.1 (12.0)
68.9 (6.4)
33.4 (3.1)
29.1 (2.7)
182.9 (17.0)

FIGURE 14. - Marion 184-M initial footcandle readings.

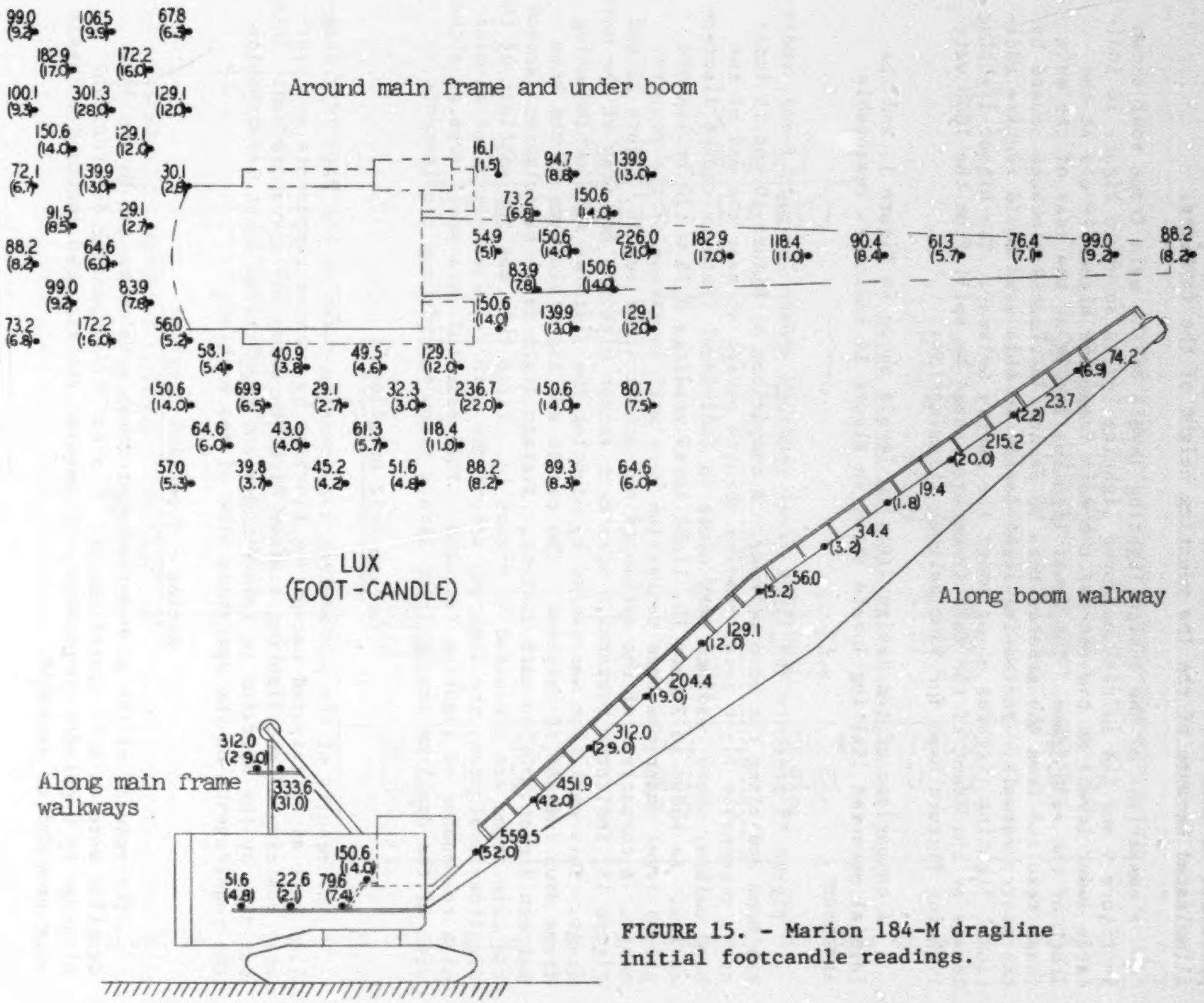
Around main frame and under boom
99.0 (9.2)
106.5 (9.9)
67.8 (6.3)
182.9 (17.0)
172.2 (16.0)
100.1 (9.3)
301.3 (28.0)
129.1 (12.0)
150.6 (14.0)
129.1 (12.0)
72.1 (6.7)
139.9 (13.0)
30.1 (2.8)
91.5 (8.5)
29.1 (2.7)
88.2 (8.2)
64.6 (6.0)
99.0 (9.2)
83.9 (7.8)
73.2 (6.8)
172.2 (16.0)
56.0 (5.2)
16.1 (1.5)
94.7 (8.8)
139.9 (13.0)
73.2 (6.8)
150.6 (14.0)
54.9 (5.1)
150.6 (14.0)
226.0 (21.0)
182.9 (17.0)
118.4 (11.0)
90.4 (8.4)
61.3 (5.7)
76.4 (7.1)
99.0 (9.2)
88.2 (8.2)
83.9 (7.8)
150.6 (14.0)
150.6 (14.0)
139.9 (13.0)
129.1 (12.0)
58.1 (5.4)
40.9 (3.8)
49.5 (4.6)
129.1 (12.0)
150.6 (14.0)
69.9 (6.5)
29.1 (2.7)
32.3 (3.0)
236.7 (22.0)
150.6 (14.0)
80.7 (7.5)
64.6 (6.0)
43.0 (4.0)
61.3 (5.7)
118.4 (11.0)
57.0 (5.3)
39.8 (3.7)
45.2 (4.2)
51.6 (4.8)
88.2 (8.2)
89.3 (8.3)
64.6 (6.0)
LUX
(FOOT-CANDLE)
Along main frame walkways
312.0 (29.0)
333.6 (31.0)
150.6 (14.0)
51.6 (4.8)
22.6 (2.1)
79.6 (7.4)
Along boom walkway
559.5 (52.0)
451.9 (42.0)
312.0 (29.0)
204.4 (19.0)
129.1 (12.0)
56.0 (5.2)
34.4 (3.2)
19.4 (1.8)
215.2 (20.0)
23.7 (2.2)
74.2 (6.9)

FIGURE 15. - Marion 184-M dragline initial footcandle readings.

performed in this area. The vertical walls of the tub and crawlers were well illuminated because of the low mounting height of the fixtures.

A comparison of the design lighting levels on the main frame roof shown in Figure 9 and the initial measured lighting levels shown in Figure 14 indicates lower levels at the rear of the main frame and higher levels at the front of the main frame. The lower lighting levels at the rear of the main frame resulted from the greater than 50 percent estimated blockage caused by the gantry catwalk. Increasing light levels in this area would require additional lighting fixtures on or under the gantry walkway. The higher lighting levels at the front of the main frame are caused by spill from the 1000 watt lighting fixture used for boom walkway illumination.

A comparison of the design lighting levels shown in Figure 11 and the initial measured lighting levels shown in Figure 14 indicates reasonable agreement.

Figure 15 presents the light level readings around the main frame, under the boom and along the boom walkway. A comparison of Figure 10 and 15 indicates reasonable light level reading results except up near the end of the boom walkway where readings very close to individual fixtures causes discrepancies. As shown in Figure 15, light level readings 0.76 m (30 in.) above ground level under the boom centerline were well in excess of the requirements. A comparison of the estimated and actual light levels, Figure 12 and Figure 15, indicates reasonable agreement except within a few feet of the main frame. This condition was caused by mounting the fixtures with the mounting frame down instead of extended. The result was light blockage of the beam pattern directly below each fixture. Average light level calculations around the main frame are presented in Figure 16. Since this was the smallest of the draglines evaluated, the lighting around the main frame was designed to minimize the number of lighting fixtures. This resulted in a small area on either side of the dragline having light levels below the minimum requirements.

Page 7-32 Dragline

The results of the photometric measurements taken on the Page 7-32 dragline were as anticipated except for blockage by machine components and operator reaiming of one lighting fixture directly above the operators cab. This was done by the operator to reduce glare and resulted in light levels below the requirements on the operators side of the machine.

Marion - Type 7800 Dragline

The results of the photometric measurements taken on the Marion 7800 dragline were as anticipated except for minor discrepancies due to light blockage by machinery components. In general the required footcandle levels were provided or exceeded.

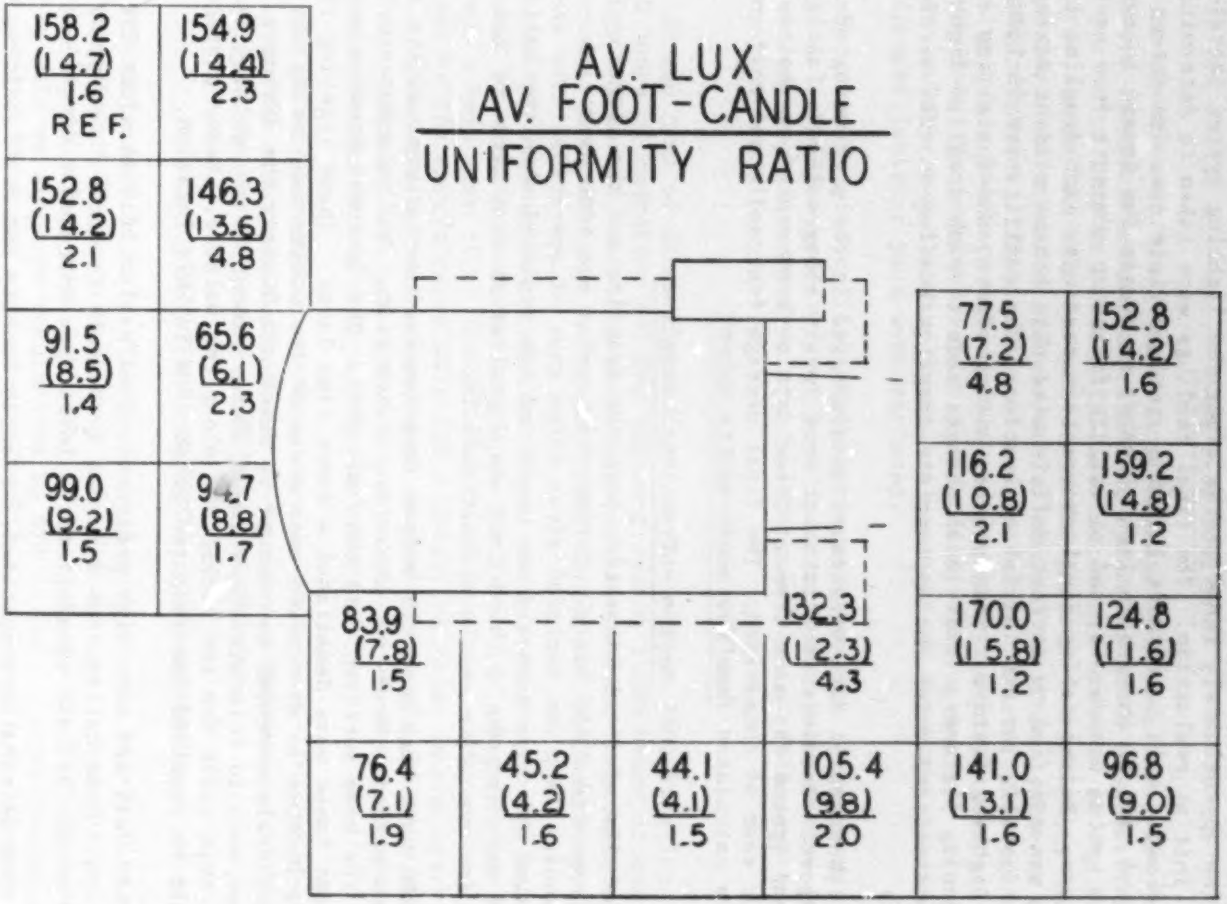
AV. LUX
AV. FOOT-CANDLE
UNIFORMITY RATIO
158.2 (14.7) 1.6 REF.
154.9 (14.4) 2.3
152.8 (14.2) 2.1
146.3 (13.6) 4.8
91.5 (8.5) 1.4
65.6 (6.1) 2.3
99.0 (9.2) 1.5
94.7 (8.8) 1.7
83.9 (7.8) 1.5
132.3 (12.3) 4.3
76.4 (7.1) 1.9
45.2 (4.2) 1.6
44.1 (4.1) 1.5
105.4 (9.8) 2.0
77.5 (7.2) 4.8
152.8 (14.2) 1.6
116.2 (10.8) 2.1
159.2 (14.8) 1.2
170.0 (15.8) 1.2
124.8 (11.6) 1.6
141.0 (13.1) 1.6
96.8 (9.0) 1.5

FIGURE 16. - Marion 184-M dragline initial footcandle readings around main frame.

FINAL LIGHTING SYSTEM ADJUSTMENT AND EVALUATION

Phase III of the project involved taking final light level readings on each dragline approximately three months after the lighting system installation and initial evaluation. The final readings were taken to determine the effect of changes made to correct lighting system deficiencies, to detect any unanticipated radical changes in light levels, to assess the damage incurred to lighting system components, and to collect follow-up comments from each of the operators. Before taking final photometric readings, each dragline lighting system was modified to correct deficiencies that became evident during the system installation and initial evaluation. The modification included adjusting lighting fixture aiming points, adding visors, and installing additional lighting fixtures. Individual changes made to each dragline lighting system are discussed under the appropriate dragline heading in this section of the report.

Final photometric data were taken as discussed in the preceeding section of this report. Readings were taken at roof level, along walkways, along ladders, and around the main frame. These data were presented on photometric layouts for ease of comparison. The final average footcandle and uniformity ratios were calculated from the measurements taken.

Marion - Type 184-M Dragline

At the time of final inspection both the dragline and the lighting fixtures had operated 2,450 hours. During this period one 1000 watt high pressure sodium lamp was replaced after three days of operation. The second lamp operated for approximately one month and was replaced when the ballast failed and was changed. A third lamp was installed at that time and had been operating for over five months without failure.

One 400 watt high pressure sodium lamp required replacement within the observation period. We do not know its service life. Two incandescent lamps placed on the boom survived less than one week. The fixtures housing these incandescent lamps were demolished a short time later. These lighting fixtures were located in an exposed area close to the cables supporting the boom. The support cable movement was enough to reach and destroy the fixtures. No attempt was made to relocate these two fixtures closer to the walkway because the hoist rope cable for the bucket ran along the walkway. Heavy protective cages would be required for fixtures to survive in this location.

One 480 volt 400 watt high pressure sodium ballast failed after 750 hours of operation. This ballast was returned to Phoenix Products Company and then forwarded to the ballast manufacturer. Inspection revealed a burned coil.

One 1000 watt ballast operated for approximately one month before failure. The replacement ballast did not operate the lamp. A third ballast was installed and the lamp operated properly. The 1000 watt ballasts were scrapped or lost at the mine site and the cause of failure could not be evaluated.

Page 7-32 Dragline

At the time of final inspection the Page 7-32 dragline accumulated 590 hours of operation and the lighting system 95 hours of operation. During this period no lamp or ballast failures occurred. On four of the boom mounted fixtures a mounting bolt was not tightened properly. Tightening corrected this error. A lack of stiffness was also noted in three isolators of the SRS-100M fixtures. Examination of the isolators revealed that some of the mounting bases had been welded to the supporting angle iron instead of bolting as intended. The excessive heat generated by welding damaged part of the rubber isolator pad allowing excessive movement of the light fixture head. The damaged isolator pads were replaced.

The results of the final photometric measurements taken on the Page 7-32 dragline lighting system were in compliance with the requirements except for certain walkways discussed in the following section of this report.

Marion - Type 7800 Dragline

At the time of final inspection the Marion Type 7800 dragline accumulated 2,200 hours of operation and the lighting system 1,665 hours of operation. During this period, one 1000 watt high pressure sodium lamp failed and was replaced. No other lamp failure occurred during the evaluation period.

The 480 volt 400 watt high pressure sodium ballasts failed and were returned to Phoenix Products Company. The first ballast failed to start and operate a lamp when first installed and was replaced. Inspection of this ballast by the manufacturer revealed a defective triac in the starting circuit. The second ballast accumulated several hours of operation before failure. This ballast was not returned to the manufacturer for failure analysis because it was lost by the operator.

The final photometric readings were in accordance with the required footcandle levels except at the top end of the boom. This unique lighting problem is discussed in the following section of this report.

OBSERVATIONS, COMMENTS, AND DISCUSSION

The objective of this effort was to determine the feasibility of lighting draglines to the Proposed Mandatory Safety Standards. These Proposed Mandatory Safety Standards were published in the January 13, 1977 "Federal Register" by MSHA as proposed regulations to CFR 77.207. In performing this task substantial effort was made to provide illumination as specified in CFR 77.207, paragraph d, except items 1 and 2 (interior walkways and other interior areas) which were specifically excluded by the contract. The proposed regulations are summarized in Figure 1.

A review of the data indicates the technical feasibility of illuminating most of the specified areas on and around draglines, in accordance with the proposed regulations, by the systematic design and application of commercially available lighting equipment. In most instances the lighting systems evaluated were well received by mine operators and dragline personnel. Practical problems encountered are discussed below by the specific areas of the dragline requiring illumination in the proposed regulations.

Illumination Around Main Frame

Illuminating the area 6.1 m (20 ft) around the main frame presents no major technical lighting system design or installation problems. However, measuring the light levels in accordance with the requirements was very difficult in some instances. Draglines used in this demonstration operated on retreating ledges alongside the pit. This resulted in two sides of the machine--regardless of its rotational position, always being at the pit edge. There was not enough room around any of the machines to layout the complete grid system required for light measurements on the corners and centers of every 9.3 m^2 (100 ft^2) area. It was necessary to layout the grid system on only one side of the machine and then measure those light levels. The machine was then rotated to a new position and the process of grid layout and light level measurement repeated.

While taking one set of readings, the Marion Type 184-M dragline operated at the end of a retreating ledge with the pit along one side and the spoil pile along the opposite side. Spoil was being discharged at the maximum dump height of the dragline and then pushed back by a dozer. The result was a very high, steep spoil pile with its base less than the necessary 6.1 m (20 ft) from the main frame. This meant climbing over spoil a short distance to get 6.1 m (20 ft) away from the dragline for light readings. The close proximity and height of the spoil pile provided a huge reflective surface resulting in higher light level readings than would have been measured if the spoil pile were not present. It presented a hazard from tumbling rocks and slides to personnel taking the light readings. Under the proposed regulations, illumination of the spoil pile is not required.

Taking a complete set of light level measurements around the main frame in accordance with the proposed requirements will be difficult, time consuming, and could be hazardous to personnel under certain mining conditions. One possible alternate method for measuring the light levels around the main frame is to take two sets of readings. The first set to be taken at a distance of no more than 0.9 m (3 ft) from the main frame and the second set at no less than 6.1 m (20 ft) from the main frame. Both sets of readings would be taken parallel to the main frame side, 0.8 m (30 in.) above ground level, on a horizontal plane and at least every 3.1 m (10 ft) or a minimum of four evenly spaced readings on each side. The machine operator would rotate the machine to the most accessible position for taking the light readings. Average light levels and uniformity ratios would remain as proposed. A second possible alternate method for measuring the light levels around the main frame is to set reading markers at 1.5 m (5 ft) spacings along a straight line projected through the center of rotation of the machine. Readings would be taken at 0.8 m (30 in.) above ground level starting at the marker closest to the main frame, but not under it. At 1.5 (5 ft) spacings five readings would be taken approximately the required 6.1 m (20 ft) from the dragline then the main frame would be rotated through a fixed angle, possibly 10 degrees, and another set of five readings taken. This process could be repeated until readings were taken completely around the machine. Average light levels and uniformity ratios would be calculated from adjacent sets of readings.

Area illumination around the main frame was well received by both the mine operators and the operating personnel for each dragline. The two exceptions were machine operator complaints. Light sources mounted on the boom or main frame with the source light visibile from the operators cab caused disability glare. Light sources placed in close proximity and especially directly above the operators cab caused veiling brightness in raining or foggy weather and when air born dust conditions were severe. This condition must be minimized by careful consideration of lighting fixture mounting and aiming during lighting systems design.

Illumination Under the Main Frame

Illuminating work or travel areas beneath the main frame presents design, installation, and light measuring problems. These problems result from the low ground clearance, the shape of the underside of the main frame and the physical restrictions resulting from the dragline tub and crawlers/feet. Locations for mounting lighting fixtures under the main frame are very limited. Lighting fixtures must be located and mounted to assure protection from the debris at the pit edge which they are likely to strike when the machine rotates. Low ground clearance severely restricts the lighting system design in meeting the proposed requirements. Making light measurements in accordance with the proposed requirements is not only difficult when working in the confined space, but becomes impossible as the machine ground clearance approaches 0.8 m (30 in.). Laying out the grid system cannot be done in a standing position and taking light measurements 0.8 m (30 in.) from the ground can place the light meter closer to the machine underside than to the ground. The low fixture mounting height can result in the light meter being just a few feet from a lighting fixture. The result is uniformity ratios requirements could not be met. Under the conditions of low fixture mounting height and confined surroundings the vertical footcandle component of light present becomes important for the seeing tasks performed. This element of the light present is not evaluated by the current measuring method.

One possible alternate method for measuring the light levels under the main frame is to take readings no more than 0.9 m (3 ft) underneath and parallel to the main frame sides. Measurements would be spaced no more than 3.1 m (10 ft) apart with at least four readings on each side. The readings could be taken at ground level with the meter angled for maximum values. All readings should be no less than 53.8 Lux (5 ft-c) with the proposed average intensity and uniformity requirements eliminated. A second possible alternate method for measuring the light levels under the main frame would be to extend the straight line/rotating machine method discussed under Section A above under the main frame. Readings under the main frame could be taken at ground level with the meter angled for maximum values. The 53.8 Lux (5 ft-c) minimum requirement could be maintained if the proposed average intensity and uniformity requirements were eliminated.

Illumination Along Walkways and Ladders

In the effort expended on this project the requirements were interpreted to include ladders as walkways. Ladders and walkways present difficult lighting problems. Walkways along the sides of the main frame require illumination because they are frequently traveled and often become storage areas for grease and oil cans, tool boxes, spare parts, rope, and chains. The required illumination for these areas can be provided for by proper mounting and aiming of the area light fixtures mounted on the roof of the main frame. Walkways along the roof of the main frame can be illuminated from lighting fixtures mounted high up on the gantry. Walkways along the boom, except near the top can be illuminated by lighting fixtures mounted high up on the gantry. These geometrical situations present conditions suitable for the application of floodlighting equipment to meet the required lighting levels. However, ladders and walkways near the top of the boom and around the top of the gantry present the physical restraints of low light fixture mounting height, limited mounting locations, and confined space. Illumination for ladders is required for safety. However, the proposed measurement method used for walkways illuminated by floodlighting cannot be applied to ladders. The rungs and handrails should be illuminated without shadowing caused by the person climbing the ladder. The proposed measurement method also eliminates the possibility of illuminating ladders and walkway gratings from below or behind. A solution to this measurement method problem might be to offer the option of using the proposed measurement method or an alternate method of measurement. The alternate method for measuring the light levels along walkways and ladders could be to take readings at the surface to be measured with the meter angled for maximum values. A 53.8 Lux (5 ft-c) minimum requirement could be maintained if the average intensity and uniformity requirements were eliminated. In discussions with mine personnel, it appears that certain walkways would not be used during night time hours. Routine maintenance of the boom is apparently limited to daylight hours. Perhaps exterior walkway lighting should only be required during periods when people are present. This modification of the requirements would reduce operator disability glare from boom mounted walkway lighting fixtures during digging operations of the dragline.

Illumination Under the Boom

With very few exceptions illumination beneath the boom will be in accordance with the proposed requirements on existing draglines involved in night time operations. Lighting beneath the boom in the pit is provided by boom mounted lights. The light levels required for normal production exceed the

10.7 Lux (1 ft-c) required for safety. However, boom mounted fixtures should be mounted and aimed so that direct source light is not visible to the dragline operator in the cab.

Illumination Along the Hoist Rope Line

The proposed standards include no lighting requirements for illumination along the hoist rope line. However, every dragline operator expressed concern with the potential danger of pulling the hoist rope line knot through the point sheave severing the hoist rope line. Severing the hoist rope line certainly creates a hazard to operating personnel. The dragline operators ability to judge the maximum dumping height of the bucket and the relative position of the hoist rope line knot to the point sheave can be significantly improved by the application of lighting. Perhaps a minimum light level requirement perpendicular to the hoist rope line in the direction of the operator should be specified and a measurement method developed.

CONCLUSIONS AND RECOMMENDATIONS

As demonstrated by the test results of the lighting systems developed and evaluated under this effort, it is feasible to illuminate the specific areas on and around surface mine draglines in accordance with the proposed MSHA requirements by the systematic design and application of suitable lighting systems incorporating commercially available lighting equipment with the possible exception of some work or travel areas beneath the main frame, ladders, and certain walkways. It is impossible to measure the required light level at the specified 0.8 m (30 in.) from the surface to be measured beneath the main frame when the ground clearance is only 0.6 m (2 ft). The combination of low lighting fixture mounting height and physically confined space tend to increase the importance of the vertical component of light necessary to be seen by a person outside the area and to perform the simple functional seeing tasks of self orientation and personal mobility. These same conditions of low lighting fixture mounting height and confined space also exist on some exterior walkways, catwalks, and ladders on the main frame and boom. Since the illumination under the rear of the main frame was adequate for functional tasks performed in this area including tending of a trailing cable, it is recommended that alternate methods of light measurement be evaluated for these areas including the possibility of angling the light-sensitive cell for the maximum reading at surface level. This method of light measurement would allow for illuminating ladders from behind and below. It would also provide for illumination of walkway gratings and safety railings from beneath.

Under actual dragline mining conditions, measuring the light levels around the main frame in accordance with the proposed requirements was difficult, time consuming, and exposed personnel to hazards presented by the spoil pile and pit edge. Additional effort should be made to develop a measurement method that would be safer and more practical under actual mining conditions. Spoil piles in the immediate vicinity of the machine should be illuminated.

Walkway and ladder illumination levels and measurement methods should be reviewed to determine the necessity for lighting requirements when personnel are not present and develop alternate methods of light level measurement more representative of functional seeing tasks.

The dragline operators ability to judge the maximum dumping height of the bucket and the relative position of the hoist rope line knot to the point sheave can be significantly improved by proper illumination. Since severing the hoist rope line creates a hazard to operating personnel, requirements for illuminating the bucket and hoist rope line should be developed and included in the proposed MSHA regulations.

High intensity discharge light sources were selected over incandescent light sources for most applications on surface mining draglines because of their high luminous efficacy, rugged shock and vibration resistant construction, and long life. The frequency and amount of time expended servicing lighting equipment mounted on draglines is a major factor in the practical application of lighting systems to surface mining draglines. The use of a minimum number of rough service lighting system components capable of surviving in the environment is important to maintaining the light levels required on a long term basis.

TITLE OF PAPER: Lighting for Large, Mobile,
Surface Mining Equipment

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Mr. Wahl also directed and participated in the design and construction of large electromagnetic pumps for use by HEDL at Richland, Washington and Argonne National Labs at Idaho Falls, Idaho.

Mr. Wahl directs in-house and commercial projects related to electrical engineering, and was responsible for conduct of this USBM-sponsored project to design lighting systems for lighting large mobile surface-mining equipment.

LIGHTING FOR LARGE, MOBILE, SURFACE MINING EQUIPMENT

by

Martin H. Wahl[1]

ABSTRACT

This paper includes the design, installation, and demonstration of lighting systems to meet the specifications of regulations proposed in Volume 42, No. 9, Section 77.207 of the January 13, 1977 issue of the Federal Register. Specifically, the demonstration was for the "Illumination of Electric Powered, Mobile Surface Mining Equipment" that included a 176 cubic yard dragline (B.E. 3270), a 60 cubic yard dragline (B.E. 1450), and a 105 cubic yard shovel (Marion 5900). All equipment is owned by AMAX Coal Company, and is located in southern Illinois.

Areas under the boom and around the main frame were designed to meet the minimum average illumination intensity of one (1) and five (5) footcandles (fc) respectively, at the specified uniformity ratio of 10/1. Operation of the system provided for a manual or automatic control, the automatic control being provided with a photoelectric device.

Special mountings were constructed for installation of the luminaires on the machines. These mountings were designed to withstand the forces generated in the operation of a swinging boom and also to provide for ease of installation. Attention was also given to the bulb supports to prevent a separation of the bulb and socket.

High pressure sodium luminaires were used for the area illumination because of the high output to watts ratio. The high pressure sodium replaces mercury vapor luminaires on the 60 cubic yard dragline and the 105 cubic yard shovel. The 176 cubic yard shovel was in the final stages of construction and utilized a mix of mercury vapor and high pressure sodium.

Demonstration of the project extended over a period of three months, with a monthly visit to the sites to record operating data and personnel interviews. The consensus of the mining personnel was favorable for use of high pressure sodium over mercury vapor lighting systems. One comment indicated work had proceeded through foggy periods where previous shutdowns had been required when mercury vapor lighting was used.

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ACKNOWLEDGEMENTS

The work presented in this paper was *authorized by the Bureau* of Mines under a contract titled, "Illumination of Electric-Powered, Mobile, Surface Mining Equipment". Contract Officer is Alan Bolton, Contract Specialist William Mundorf and Technical Project Officer William Lewis. The cooperating mine is AMAX Coal Company, Southern Division, with headquarters at Evansville, Indiana. Subcontractor for the design was General Energy Development Corporation (GEDC).

INTRODUCTION

The Federal Register Volume 42, Number 9, January 13, 1977, proposed rules for the illumination of draglines and shovels used in surface coal mining operations. An inquiry was issued for a study of "Illumination of Electric-Powered, Mobile, Surface Mining Equipment", to demonstrate the installation and operation of lighting systems designed to the specifications of the proposed rules. A contract was awarded to Mine Safety Appliances Company for this work. Specifically, the work reported here involves area lighting under the boom and around the main frame of the machines.

Two draglines and one shovel were selected to participate in this project. They were the B.E. 1450, 60 cubic yards and B.E. 3270, 176 cubic yards, draglines located at the Delta Mine of AMAX and a Marion 5900, 105 cubic yards shovel located at the Leahy Mine of AMAX. A visit was made to the mines to observe on board operation of the machines, interview mine personnel, obtain layout drawings of each machine and to take photographs of each machine for reference during the lighting design stage. Some important machine information obtained for use in the design of the lighting systems is as listed in Table 1.

Utilizing this machine information, a design format proceeded to select luminaires and specify mounting locations to provide illumination to the proposed rules. These illumination levels are shown in Table 2.

LUMINAIRE SELECTION

The design program was initiated with a review of existing lighting hardware available from a selected cross section of lighting equipment manufacturers, in response to inquiries made for performance of the defined tasks. Selection of the luminaire for Area Lighting was based on sixteen criteria listed in Table 3. The rating of each luminaire was determined by a simple 1 to 10 scoring system.

TABLE 1. - Mining Machinery Dimensions

BUCYRUS ERIE 3270, 176 C.Y. DRAGLINE

Boom Angle - 36°
Boom Length - 330 feet
Boom Height from Ground - 230 feet
Operating Radius - 311 feet
House Width - 116 feet
House Length - 123 feet
House Height - 60 feet

MARION 5900, 105 C.Y. SHOVEL

Boom Angle - 45°
Boom Length - 210 feet
Dumping Height - 130 feet
Dumping Radius - 213 feet
House Width - 60 feet
House Length - 87 feet
House Height - 80 feet

BUCYRUS ERIE 1450, 60 C.Y. DRAGLINE

Boom Angle - 38°
Boom Length - 250 feet
Boom Height from Ground - 170 feet
Operating Radius - 227 feet
House Width - 44 feet
House Length - 90 feet
House Height - 30 feet

TABLE 2. - Proposed Federal Standards

Location	Avg. FC	Uniformity ratio
1. All area 20' in all directions from the main frame, including all work or travel areas beneath the main frame	5.0	10/1
2. Exterior walkways on board draglines, shovels, and wheel excavators	5.0	10/1
3. The area beneath the boom 20' from the main frame to the farthest point the equipment is capable of excavating or discharging material	1.0	10/1

TABLE 3. - Luminaire Selection Criteria

	Weight
1. Lamp Orientation	4
2. Fixture Material	3
3. Reflector Design	3
4. Mounting Method	5
5. Light Source	1
6. Lamp Replacement	5
7. Photo Electric Controls	1
8. Low Temperature Starting	1
9. Vibration	5
10. Dust and Weatherproofing	5
11. Ballasting	1
12. Luminaire Angling	2
13. Standard Fixture Cost	1
14. Modification Cost	4
15. Time to Modify	5
16. Availability	3

This 1 to 10 score, multiplied by the criteria weight resulted in the total weighted score for each manufacturer. Under this analysis, the GTE-Sylvania "Batwing" series of luminaires were selected for use in the Area Lighting. These luminaires were High Pressure Sodium (HPS).

LIGHTING DESIGN

Mathematical models were constructed to deal with the problems relating to Area Lighting. The Mathematical Models for Area Lighting systems were developed around the use of a computer programmed with all the pertinent information of the selected luminaires. There were six major data input areas necessary for the computerized mathematical models of the proposed area lighting systems. These were:

A. Size of the machine to be illuminated by height, width, and length including separate boom angle specifications.

B. Estimated heights at which luminaires are to be mounted.

C. Type of luminaires to be used, including isointensity diagrams.

D. Description of areas to be illuminated.

E. Estimated luminaire layouts and aiming angles.

Information on machine size and luminaire mounting heights was obtained from available drawings and photographs taken during visits to the AMAX mines.

The selection of luminaires was made, as previously discussed, based on comparative evaluations of sixteen criteria, with the GTE-Sylvania high pressure sodium Batwing series scoring the highest evaluation points. The areas to be illuminated around the mining equipment were proposed by MSHA in the Federal Register and included:

1. All areas 20 feet in all directions from the main frame.

2. Area beneath the boom frame 20 feet from the main frame to the farthest point the equipment is capable of excavating or discharging material. The area for boom lighting was not definitive enough for an accurate computer input as relates to the distance on either side of the boom. The area under the boom was redefined to specify the width as equal to the main frame plus forty feet.

The light loss factors were applied in three areas, as follows:

1.	Installation and manufacturing tolerance	5% loss
2.	Lamp lumen depreciation at 3/4 rated lamp life	15% loss
3.	Dirt accumulation on fixture	19% loss
	Total Light Loss	39%

Estimated luminaire layouts and aiming angles were based on known technology in establishing uniform distribution patterns for large area lighting installations. Horizontal and vertical aiming of individual luminaires were determined after analyzing computer printouts which had luminaires mounted at angles perpendicular to the ground. Horizontal and vertical aiming angles were modified with respect to set guidelines, uniformity ratios and average foot candle levels for the entire area illuminated.

Utilizing the information available for these six major data input areas, the computer analyzed each point of the areas to be illuminated on a predetermined grid pattern and then provided a printout of this information. The printout was compared with original estimates and the levels set for in the proposed MSHA regulations and adjustments were made, as required, to aiming angles, mounting location and height to determine the optimum illumination layout. With this iteration the computer again provides a printout listing the footcandles that can be expected in each area of the established grid system. An analysis of this printout will indicate whether too many or too few luminaires are being used and whether a higher or lower wattage luminaire would improve the quality of the illumination layout.

Utilizing the mathematical models and the format described, illumination systems were designed for the machines. It was found that the optimum illumination layouts utilized 1000 watt high pressure sodium luminaires for the B.E. 3270 dragline and Marion 5900 shovel and 400 watt high pressure sodium luminaires for the B.E. 1450 dragline.

The B.E. 1450 required eleven 400 watt high pressure sodium luminaires to light the areas around the main frame and under the boom. Six of these luminaires were mounted on the roof and five on the boom. Nine 1000 watt high pressure sodium luminaires were required for the B.E. 3270 dragline. Three were mounted on the roof, two on the front of the house, and four on the boom. The Marion 5900 shovel required eight 1000 watt high pressure sodium luminaires, three on the roof, one on the front of the house and four on the boom.

After approval of the designs, installation drawings providing location and aiming information were presented in an orientation at AMAX facilities. In addition, electrical diagrams provided information for wiring of the lighting system. All systems utilized 480 volts for operation of the luminaires with a central electrical panel installed for control. Automatic dusk to dawn operation was arranged for by use of a photoelectric cell.

DEMONSTRATION

Design of a lighting system is only an orderly method of prediction of its operation, based on the application of available engineering information. The integrity of the design must be verified by accepted standards of tests and measurements. To perform these tasks a photometric survey procedure was developed.

The program developed for this work included verification of the installation according to design by checking:

1. Mounting heights and distances
2. Aiming angles
3. Physical obstructions to the light patterns
4. Operation of electrical controls

To correlate the actual lighting designs with the installed systems, a portion of the ground under consideration was divided into test areas of the same grid setup as planned for the computer design printout. Readings were taken at each 10 ft. by 10 ft. grid area, with repeat measurements at a key test point with a frequency to assure stability of the system and repeatability of results. It was expected that the test readings would be much higher than the computer projections, since the lamps were new and the Light Loss Factor (LLF) of 0.61 not applicable.

Two complete field photometric surveys were conducted on each machine. The first survey was made at the completion of the installation of the lighting systems on each individual machine and the second at the end of the demonstration period. It must be noted that the installation on each machine was contingent with the time the machine may be out of production due to scheduled or unscheduled maintenance. The B.E. 3270 dragline was a new machine in the process of being constructed, so the lighting system was installed prior to its completion. The B.E. 1450 dragline and the Marion 5900 shovel lighting systems were installed when the machines were taken out of production.

The demonstration period was to be for three months, but was of different lengths of time because of the inability to install the lighting systems simultaneously on each machine. The demonstration period started at the time of the first photometric survey and was considered complete at the time of the second photometric survey. The second photometric survey was performed on all machines on the same date.

ANALYSIS

Analyses were made of the surveys to each other, to the Computer Mathematical Models (CMM), and to the Proposed Federal Standards (PFS).

A review of the computer printouts for the various trace areas under the boom and around the main frame show that the average computer calculated footcandles is greater than required by the Proposed Federal Standards. The comparative averages for the specific machines are shown in Table 4.

The above average CMM intensities in Table 4 were calculated high because they are expected to depreciate due to uncontrollable loss factors. These above average CMM intensities also represent the lighting produced from an optimum luminaire selection which dictated that mixed lamp wattages within the system would not be advantageous toward long-term maintenance of the system.

Field photometric survey No. 1 was conducted on each machine soon after the lighting systems were installed and operational. The comparative averages between the No. 1 photometric survey and the Computer Mathematical Model (CMM) for specific machines are shown in Table 5. Certain discrepancies can be noted in Survey No. 1 which are attributed to the inability to properly aim the luminaires, especially around the main frame of the machines. Obstructions and overhangs were encountered which were not evident in the review of machine drawings. For example, a 1000 watt high pressure sodium luminaire mounted on the side of the Marion 5900 had a light intensity of only 43 percent of the same luminaire mounted on the B.E. 3270 although the B.E. 3270 is a larger machine. This intensity can be increased by mounting the Marion 5900 main frame luminaires at lower points under any obstructions, although this may inhibit the ease of maintenance of these fixtures. Multiple fixtures (placed at top corners) may be a more feasible solution. Areas under the boom of all three machines had higher average intensities than predicted by the CMM and considerably above the Proposed Federal Standards.

TABLE 4. - Comparative averages
Computer mathematical models (CMM)
Proposed federal standards (PFS)

B.E. 3270

Area	Average fc	
	CMM	PFS
Under boom..................	3.2	1.0
20' from main frame, front...	16.3	5.0
20' from main frame, side....	8.3	5.0
20' from main frame, rear....	6.5	5.0

B.E. 1450

Area	Average fc	
	CMM	PFS
Under boom..................	3.0	1.0
20' from main frame, front...	9.8	5.0
20' from main frame, side....	7.3	5.0
20' from main frame, rear....	7.2	5.0

Marion 5900

Area	Average fc	
	CMM	PFS
Under boom..................	3.4	1.0
20' from main frame, front...	12.1	5.0
20' from main frame, side....	7.2	5.0
20' from main frame, rear....	7.2	5.0

TABLE 5. - Comparative averages
Photometric survey no. 1
Computer Mathematical Model (CMM)

B.E. 3270

Area	Average fc	
	Survey no. 1	CMM
Under boom..................	3.4	3.2
20' from main frame, front...	14.2	16.3
20' from main frame, side....	8.1	8.4
20' from main frame, rear....	(lumin. out)	6.5

B.E. 1450

Area	Average fc	
	Survey no. 1	CMM
Under boom..................	5.3	3.0
20' from main frame, front...	(not aimed)	9.8
20' from main frame, side....	4.0	7.3
20' from main frame, rear....	3.3	7.2

Marion 5900

Area	Average fc	
	Survey no. 1	CMM
Under boom..................	4.0	3.4
20' from main frame, front...	3.3	12.1
20' from main frame, side....	3.3	7.2
20' from main frame, rear....	3.5	7.2

The second series of field photometric survey were conducted from four to eight months after the machines had been operating with the new lighting systems. The comparative intensity averages of the two photometric surveys, the Computer Mathematical Model and the proposed Federal Standards are shown in Table 6.

TABLE 6. - Summary of comparative averages

B.E. 3270 8 months of operation

Area	Average fc Survey no. 2	 Survey no. 1	 CMM	 PFS
Under boom....................	3.6	3.4	3.2	1.0
20' from main frame, front...	15.5	14.2	16.3	5.0
20' from main frame, side....	7.4	8.1	8.4	5.0
20' from main frame, rear....	3.2	N/A	6.5	5.0

B.E. 1450 4 months of operation

Area	Average fc Survey no. 2	 Survey no. 1	 CMM	 PFS
Under boom....................	5.7	5.3	3.0	1.0
20' from main frame, front...	N/A	N/A	9.8	5.0
20' from main frame, side....	5.9	4.0	7.3	5.0
20' from main frame, rear....	(lumin. out)	3.3	7.2	5.0

Marion 5900 6 months of operation

Area	Average fc Survey no. 2	 Survey no. 1	 CMM	 PFS
Under boom....................	4.0	4.0	3.4	1.0
20' from main frame, front...	1.9	3.3	12.1	5.0
20' from main frame, side....	1.9	3.3	7.2	5.0
20' from main frame, rear....	4.8	3.5	7.2	5.0

Discrepancies noted in the second series of photometric surveys were similar to those experienced in the first surveys. Boom area readings, for example, on the B.E. 3270 in the second survey tended to average higher than the first survey. This may be attributed to the slight shifting of luminaires under vibration and shock. Point readings at the end of the boom were lower in the second survey, with a tendency for the light pattern to shift toward the main frame. Lamp lumen depreciation cannot be expected to have any measurable effect after 8 months of operation, since the sodium lamps are rated at 24,000 hours, which is equivalent to 2-3/4 years.

Several luminaires experienced maintenance difficulties during the demonstration period and required replacement of lamps and brackets. It is quite possible that luminaire aimings were disturbed during this maintenance. This would appear to have happened with the front and side lighting on the Marion 5900 which shows a degradation in light levels between Survey No. 1 and Survey No. 2.

SUMMARY AND RECOMMENDATIONS

The ability to meet the Federal Proposed Standards for area lighting appear to be easily accomplished with the hardware now on the market. In fact, the photometric surveys showed that the average intensity under the boom area was better than three to five times greater than the Proposed Federal Standards. Even applying a light loss factor of 0.61, the intensity would be two to three and one-half times as large as the Federal Proposed Standards.

The results of the lighting systems installed for illumination of area around the main frame was less definitive. The Computer Mathematical Model predicted higher levels than were achieved, although the average levels were higher for the B.E. 1450 and B.E. 3270 draglines than the Proposed Federal Standards. However, the Marion 5900 shovel light levels were less than the proposed standards on all sides, except the rear of the machine. Apparently the luminaires used for lighting the main frame encounter difficult mounting locations. It appears that main frame lighting from a luminaire mounting and aiming standpoint is more complex than assumed, and must be defined in closer detail in order to result in a more effective system.

We must note that although standard hardware was used for illumination of the large surface mining machines, they required modifications to qualify for the hostile services aboard the machines. These modifications were related to mountings and bulb supports to withstand the shock, vibration and unusual G forces encountered during the swing and excavation stages of the machines.

The results of the lighting demonstration indicate that a Computer Mathematical Model approach can be an effective tool in designing lighting systems for electric-powered, mobile, surface mining equipment. The tangible results of the photometric surveys of the areas under the booms of the three machines demonstrate the feasibility of this approach. From an illumination standpoint, the luminaires are capable of providing more than enough light to meet the

Proposed Federal Standards for lighting around the main frame. However, because mounting the luminaires on the machine roofs does encounter obstructions, the mounting of these luminaires on the sides of the machines will result in a better lighting pattern, but will do so at a sacrifice in the ability to provide maintenance to the fixture.

This presentation has dealt with work involved in the design, installation, and demonstration of lighting systems to a specification. The specification was proposed to provide a uniform set of standards that would result in a level of illumination that would enhance safety in the designated work areas. Other than the accumulation and statistical evaluation of long term data on the safety of an operation, the comments of the workers can serve as a gage for the operations. Some workers' comments received during field evaluation and interviews heartily endorse the illumination systems. A cross section of the comments are:

1. Wouldn't be without the new system. The new system prevented a couple of shutdowns due to fog.
2. Looks like a graveyard without. Didn't think new system would make any difference, now wouldn't go back to old system. Dust is more of a problem with old system. (Old system is mercury vapor.)
3. No difficulty with new system, adds a lot of light. Not safe without side and rear lights. Good light in pit. Can't get too much light. New system is a lot safer. Old system is not safe by itself. 100% improvement.
4. The lights have been on all the time. The operators think they can't run without the new lights. The project has been worthwhile.
5. Helps with fog. Crews like them.

If the working conditions of large mobile surface mining equipment can be improved, then we must assume that safety is improved. Along with improved working conditions, the flip side can mean increases in productivity. Increased safety and productivity are hypothesized due to adequate levels of lighting. We feel the long term records will verify this assumption.

TITLE OF PAPER: **Definition of Illumination Requirements for Underground Metal and Nonmetal Mines**

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This paper was not presented at the conference since the program stressed underground coal mines. However, the paper is included in the proceedings because some of the principles described, although intended for metal, non-metal mine applications, may be potentially useful to coal mine operators.

DEFINITION OF ILLUMINATION REQUIREMENTS FOR UNDERGROUND METAL AND NONMETAL MINES[1],[2]

by

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and

James M. Peay[4]

ABSTRACT

This study presents the analysis of underground work areas and tasks for the purpose of identifying the illumination characteristics of underground metal and nonmetal mines in the United States. Attention is given to the visibility requirements of underground jobs and to the illumination and reflectance characteristics of underground work areas. Attention is also given to identifying the number of people performing underground tasks and the accidents that occur to those underground workers. Experimental evaluation of visual task performance under varying levels of illumination lead to recommendations for minimal luminance levels in underground metal and nonmetal mines. The final result of this research leads to practical recommendations for improved underground lighting practices.

INTRODUCTION

The importance of good lighting to the underground miner cannot be overemphasized. In addition to the obvious benefits of improved worker morale, available studies (Trotter, 1977) have shown that good lighting reduces accidents and increases productivity. However economics will not allow the general level of lighting in a mine to approach the levels found in most factory worksites. Therefore, the light levels used in underground mines should be based upon the minimal luminance levels necessary for safe performance of critical mining tasks.

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[1] This research was supported by the U.S. Bureau of Mines under Contracts J0387230, and J0319022.

[2] The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or of the U.S. Government.

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The basic research needed to establish minimal luminance requirements for safe job performance in underground coal mining was performed by Hitchcock (1973). This research identified the required minimal luminance levels for a number of visual tasks associated with mining jobs in both conventional continuous and longwall coal mining methods. From the findings of this research, a common minimal luminance level was specified for all underground coal mining.

Initial consideration of the illumination needs of workers in underground metal and nonmetal mines would suggest that adoption of the coal mining luminance levels would be sufficient. Certainly miners in metal and nonmetal mines work in similar conditions to those in coal mines. That is, miners in both types of mines typically work in confined spaces with only a cap lamp providing illumination. However, closer examination quickly reveals major differences between coal mines and metal and nonmetal mines. The greater variety of mining methods in the latter industry suggests a greater variety of jobs as well as a greater variety in the size and configuration of the working spaces. In addition, the wide variety of commodities extracted by metal and nonmetal miners suggests a wider range of reflectances of the underground surfaces than would be found in coal mining.

In light of the apparent differences between coal mining and metal and nonmetal mining, the U.S. Bureau of Mines has embarked on a program of research to identify the specific illumination characteristics of underground metal and nonmetal mines (Crooks, et al; 1980). The focus of this research is on the underground work locations and worker activities where the intent has been to identify the illumination needs of the work locations and activities.

The objectives of the research are (1) to identify the illumination characteristics of underground jobs and work locations, (2) to identify the visual tasks of underground jobs, (3) to specify minimal luminance requirements for safe work, and (4) to suggest improvements for safety in metal and nonmetal jobs and work locations.

ANALYSIS OF UNDERGROUND WORK AREAS AND TASKS

This study includes analyses of six distinct but closely related matters. The first analysis considered the underground locations where miners perform their jobs. This analysis included identification of the major categories of underground work locations within metal and nonmetal mines, followed by detailed on-site observations and evaluation of a carefully selected sample of work sites. Illumination, sound, and atmospheric measurements were made and the number, type, and locations of luminaires and mining machines were identified at each location. In addition, the work activities being performed at the location were identified. This analysis of work locations provided the basis for the comprehensive description of the illumination characteristics of underground work locations in metal and nonmetal mines.

The second analysis of the study concerned the illumination and visibility characteristics of the rocks and minerals that constitute the majority of the surfaces found in the mines. A Mine Illumination Laboratory was used to determine the directional light distribution (goniophotometric) properties of samples of rocks and minerals from a wide variety of metal and nonmetal mines. This laboratory (1) allowed the time necessary for detailed goniophotometric measurements and (2) provided the highly accurate instruments required for these measurements. Analyses of these goniophotometric characteristics provided the basis for identifying the reflectances that are encountered in metal and nonmetal mines.

The third analysis of this study focused on the jobs that underground workers perform in this industry. The intent of this analysis was to identify the specific tasks that are performed by the various workers, especially those tasks that are impacted by the illumination present in the underground work locations. Through both on-site observations of work activities and structured interviews with experienced miners, the tasks and activities that constitute the underground work operations were identified.

The fourth analysis of the study focused on the accidents occurring in underground metal and nonmetal mines and on the employment distribution across this industry. The focus of this latter analysis was to identify the number of people performing the various underground tasks and the accidents that occurred to those underground workers.

The fifth analysis concerns the visual tasks that are associated with the underground work activities. The purpose of this analysis is first to identify the visual tasks and then to determine experimentally the lowest luminance under which the visual tasks can be performed.

The product of the sixth analysis is the recommendations for minimal luminance levels in underground metal and nonmetal mines. The final analysis is a synthesis of the results from the five previous analyses, plus results from other research studies and standards of industrial illumination.

We now turn to a discussion of the specific conclusions that may be drawn from the analyses performed to date.

THE UNDERGROUND WORK ENVIRONMENT

Analysis of the underground working environment suggests that the categories of work locations shown in Table 1 constitute a useful taxonomy of work stations that encompass the vast majority of underground work areas in metal and nonmetal mining.

With regard to illumination, analyses of the underground work environment indicate that although some general similarities exist, there is great variability in the many characteristics of work sites in underground metal and nonmetal mining. This variability exists both between different mines and within a given mine. In general, we found that underground work environments differ significantly in surface luminances and reflectances, output of luminaires and types of visual impairments that are present.

Production and development sites have lower reflectance, lower output luminaires, lower luminances, and are more likely to have visual impairment due to aerosols or hydrosols, than do permanent work sites such as ore transfer and processing stations and maintenance shops. Additionally, production and development sites are characterized by a significant number of visual impairments, of which direct glare and the scattering of light due to the presence of aerosols and hydrosols appear to pose the greatest problems. Aerosols and hydrosols often obscure the face, and the scattering of light reduces apparent luminance.

Three-fourths of all work sites measured have surface reflectances of less than 30%. Reflectance varied significantly among the measured mines. Direct glare from light sources is a problem when the operator must work between luminaire and task, when luminaire design is poor (e.g., bare lamps), or where two or more workers are in close proximity and glare from cap lamps becomes a problem.

There are also significant differences in the sizes of the openings, ranging from 4' x 4' x 10' development raises to 125' x 200' open stopes. The height of most underground work locations is relatively uniform, with a median of eleven feet. However, the width and depth of these locations varies greatly between mines and within some mines. These variations in size of openings are positively correlated with the luminances of the surrounding area, probably due to the higher output luminaires generally used in the larger openings.

Perhaps the most significant finding regarding the work environment is the wide variety of operations performed in any given work site. As we will suggest, the work activity being performed, rather than the work site itself should be the primary focus of any illumination standards for underground metal and nonmetal mines.

TABLE 1. - Categories of underground work locations

Production sites
  . Faces
  . Stopes

Development sites
  . Faces
  . Exploration
  . Construction

Haulage sites
  . Loading sites
  . Haulage ways
  . Dump sites
  . Skip pockets

Ore processing sites

Miscellaneous sites
  . Shaft landings
  . Maintenance shops

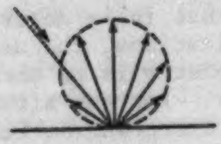
REFLECTANCE OF METAL AND NONMETAL ROCKS AND MINERALS

There is no single number that fully describes the reflectance of a surface. For above-ground applications, the use of a single reflectance obtained from a standardized geometry is an acceptable approximation for painted walls or carpeted floors. But the situation underground is far more complex. The directional light distribution (gonioreflectance) of rocks and minerals varies with the source angle, angle of view, presence of dust or water, and the reflecting characteristics of the surface. The range in gonioreflectance for any given sample can be tremendous. The ratio of highest to lowest gonioreflectance can be more than 10:1 for shale or sphalerite and as little as 2:1 for dolomite. Water is a major contributor to the variance for most rocks and minerals. At most viewing angles, water causes a 25% to 50% reduction in the gonioreflectance but the complimentary angle can increase the gonioreflectance, in some cases to over 100%. Surface moisture can be a significant source of reflected glare if the wet areas are sufficiently large. (The surface must also be brightly lit and the operator at the complimentary angle position.)

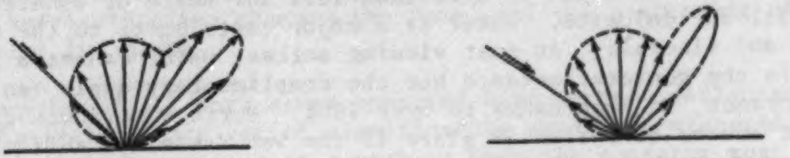
Compound reflection types are illustrated in Figure 1. Most dry rocks and minerals are matte diffuse reflectors and when wetted become diffuse and spread reflectors. A few become diffuse and specular reflectors when wet and are the most likely to cause visual impairment due to reflected glare. Gunite and white wash are diffuse reflectors which may be used to improve the visual environment.

Most mines are in a single major rock or mineral type (whose gonioreflectance, however, may be highly variable). A few mines have several major rock or mineral types present. If these types are significantly different in gonioreflectance, that mine will face tremendous difficulties in providing the optimal amount of illumination for any given task. Using the gonioreflectance data shown in Figure 2, the lighting that is adequate for development activities in dry dolomite will have to be increased approximately 400% to achieve the same luminance levels for production work in wet sphalerite. Or, if the equipment lighting is designed to provide adequate luminance production in wet sphalerite (worst case), more illumination will be provided than is cost-effective or necessary at other work sites.

The range of gonioreflectances found within a given mine also has implications for the enforcement of minimal luminance standards. For example, a jumbo drill with a given set of luminaires could be in compliance working in dolomite or feldspar and out of compliance in sphalerite or shale at the same mine. The differences among rock and mineral types are such that it may be cost-effective to tailor equipment lighting systems to particular gonioreflectance ranges.



Matte diffuse



Diffuse and spread

Diffuse and specular

FIGURE 1. - Examples of types of reflection observed in the mining illumination laboratory.

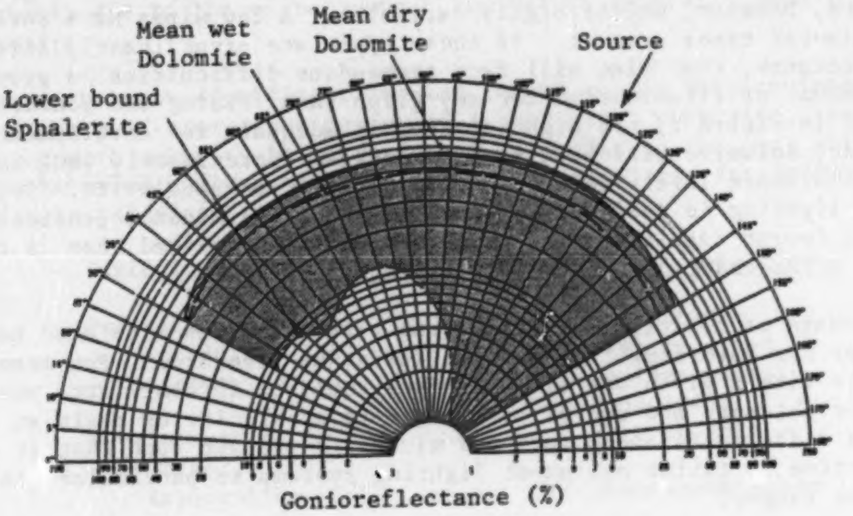


FIGURE 2. - Estimate of the mean gonioreflectance of faces at a single mine (source angle 120°).

UNDERGROUND WORK ACTIVITIES

During the course of the current research, we determined that the typical classification of work activities according to job title would not be useful. Analysis of a large sample of job titles revealed that many persons holding different job titles perform the same work activities. Conversely, people having the same or similar job titles often perform entirely different work activities. Accordingly, we chose to consider the unit operations being performed. Analysis indicated that the vast majority of work activities in metal and nonmetal mining are encompassed by the unit operations listed in Table 2.

TABLE 2. - Categories of unit operations

DRILLING

- Jackleg Drilling
- Raise Drilling
- Jumbo Drilling
- Stoper Drilling
- Ring Drilling
- Rotary Drilling

GROUND SUPPORT

- Rock Bolting
- Timber Post Erection
- Gunnite/Shotcreting
- Timberset Assembly
- Cribbing
- Sandfilling
- Preparing Work Area

LOADING

- LHD Operation
- Slusher Operation
- Overshot Loader Operation
- Manual Shoveling
- Chute Pulling
- Gathering-Arm Loader Operation

HAULAGE

- Train Operation
- Truck Operation
- Shuttle Car Operation
- Conveyor Operation/Maintenance
- Tugger

MAINTENANCE

- Shaft Maintenance
- Machine Maintenance
- Roadway Maintenance
- Track Maintenance

SERVICES

- Pipe Installation/Repair
- Ventilation Control Installation/Repair
- Electrical Installation/Repair

CONSTRUCTION

- Concreting
- Steel Construction
- Timber Construction

BLASTING

- ANFO Loading/Blasting
- Stick Powder Loading/Blasting

EXPLORATION

- Diamond Drilling
- Surveying
- Sampling

CONTINUOUS MINING

- Continuous Miner Operation
- Cutter Bar Operation

HOISTING

- Man Cage Operation
- Ore Skip Operation

SUPERVISION

- Supervising/Coordinating Workforce
- Safety Inspecting

UNDERGROUND ORE PROCESSING

- Ore Crushing

Although we analyzed many aspects of the unit operations performed by underground workers, including physical demands, training requirements, and time requirements, we focus here on the unit operations with inherent exposure to risk and with high visual demands placed on the worker. It will be seen that these activities are also critical in terms of productivity. By these criteria, the critical unit operations are:

Feed drilling
Jumbo drilling
Rock bolting
Preparing work area
L.H.D. operation
Slusher operation
Manual shoveling
Train operation
Conveyor operation and maintenance
Machine maintenance
Pipe installation and repair
ANFO loading and blasting
Stick powder loading and blasting
Safety inspecting

The visual abilities most frequently required in the performance of the aforementioned tasks were: depth perception (72%); accommodation (64%); far acuity (43%); near acuity (36%); peripheral vision (36%); and color discrimination (7%). From this listing, it is evident that some critical tasks make very low demands upon the visual system, while others may require the exercise of several visual capabilities in concert. Manual shoveling, for instance, can seemingly be performed satisfactorily under visually disadvantageous conditions, while jumbo drilling, L.H.D. operation, work site preparation, loading and blasting, and safety inspection bring into play the full spectrum of visual discrimination potential. One may conclude, therefore, that certain of these critical operations should be done by trained personnel with intact visual systems if safety and productivity criteria are to be met.

Our analyses have also shown that workers' ratings of the relative degree-of-hazard inherent in a unit operation is significantly and inversely correlated with the amount of luminance associated with that operation. Further, the accidents occurring in specific unit operations are inversely correlated with the amount of luminance. In other words, those unit operations that are perceived as being hazardous, and that do have higher than average numbers of accidents, are often performed in areas with lower luminance levels.

Moreover, our analyses indicate that there is currently no apparent relationship between the type of luminaire typically used for a unit operation and the visual demands of that operation. Unit operations with frequent visual demands were just as likely to use only cap lamps as to use high-output types of luminaires. For operations requiring near acuity, the cap lamp is probably quite sufficient. However, the lack of relationship between luminaire type and visual demand should attract attention when considering unit operations requiring far acuity, depth perception, and wide fields of view.

CRITICAL MINING ACTIVITIES

We now turn our attention to accidents associated with the critical underground work activities. For purposes of this discussion, "critical" mining activities are defined as those unit operations that are associated with a high accident index. Our analysis indicated that those unit operations with the highest accident indices are concentrated in the drilling, ground support, haulage, and loading categories. A significant number of these accidents is associated with nonpowered hand tools, which points up the importance of taking a closer look at the design of these types of tools for use by underground mining personnel. Another important finding was that of all worker activities, "barring down" or "scaling" accounts for the largest percentage of deaths or fatalities in the underground metal and nonmetal mining industry. Thus, it is advised that particular attention be given to the tools, procedures, and illumination associated with that unit operation if the number of underground fatalities is to be reduced.

We stress, however, that although the accident index may highlight some unit operations as being particularly accident prone, serious attention must also be given to those unit operations which account for a large overall number of accidents. For example, maintenance has an accident index of 1.0, indicating that the "exposure" rate of accidents for that operation is average. However, because maintenance is such a widespread activity, 13 percent of all underground accidents in metal and nonmetal mining is associated with maintenance. Thus, efforts aimed at reducing maintenance accidents will go a long way toward reducing the number of people who are hurt every year.

ENVIRONMENTAL VARIABLES AND ACCIDENTS

The preceding sections have summarized many variables that are presumed, on the basis of an array of statistical analyses, to be related to general safety in the underground environment. These include various types of luminance measurement, luminaires, hazard ratings, and the like. The crucial question still remains: "How might these variables be related to the occurrence of accidents in underground metal and nonmetal mining?"

To answer this question, several of these variables were analyzed in terms of their correlations with the frequency of accident data obtained from the 1978 HSAC accident file. Table 3 presents a summary of this analysis. It is important to note that these calculations were based upon data from all unit operations in combination, not for any one unit operation in particular. They are, therefore, to be considered very general.

TABLE 3. - Correlation between beam, penumbra, floor, and surround luminance, and number of accidents for all unit operations

	Beam luminance	Penumbra luminance	Floor luminance	Surround luminance
Number of accidents	r = -.37 $p \leq 0.04$	r = -.41 $p \leq 0.02$	r = -.36 $p \leq 0.05$	p = -.32 $p \leq 0.07$

It can be seen from Table 3 that beam, penumbra, floor and surround luminance all appear to be significantly and inversely related to the frequency of accidents in underground metal and nonmetal mining. That is to say, the more luminance generally present at the working areas in the underground environment, the less the accident frequency. It is important to qualify this finding by information gained from observation of interviews with underground personnel. There is likely to be an "optimal level of luminance" such that increases in luminance are associated with decreases in accidents up to a point, at which point further increases in luminance might be associated with an increase in accident frequency, if the sources of increased luminance are not properly distributed. Presumably, and with the illumination results in mind, this may be due to glare problems. A case in point is the situation in trona mines, where miners often complain of too much light in some areas and not enough in others, and claim that this often hampers their performance.

To determine the relative contributions of these illumination variables to accident frequencies, a multiple regression analysis was performed with beam, penumbra, surround, and floor luminances as independent variables, and accident frequency as the criterion variable. The results of this analysis indicated that penumbra, beam, and floor luminances (in that order) were all significantly associated with accident frequency. According to the present data, beam and penumbra luminance account for 30% of the variance in accident frequency.

A note of caution is in order. The accident frequency data and the luminance data used in the present regression analysis are from two distinct sources. Thus, statements of casual relationships among these data are not possible. However, the results of the present regression analysis highlight the importance of illumination as a potential key factor in underground metal and nonmetal mining accidents.

CURRENT ILLUMINATION IN METAL AND NONMETAL MINING

The results of our mine visits, interviews with experienced underground workers, and illumination laboratory analyses lead us to several distinct conclusions regarding the present lumination conditions in underground metal and nonmetal mines.

Metal and nonmetal mines are characterized by great variability of illumination environment. There are significant differences in (1) the size of the opening, (2) the reflectance of the face, and (3) the luminance of the work site within any given mine. There are significant differences between mines in the width of the opening and the reflectance of the ore. In addition, across the various mining methods, width of openings also may vary significantly. There are great differences across the entire industry in the equipment used and the unit operations performed. Luminaire types and number of luminaires vary both among mines and within a given mine. The area requiring lighting also varies greatly. For example, one day it may be necessary to illuminate the full extent of a large open stope for slushing, whereas, the next day only a small corner need be illuminated for feedleg drilling.

Just as the area requiring illumination may vary, one notes that the amount of illumination required for each task also varies. The task analysis indicated that each unit operation has unique requirements for acuity, depth perception and accommodation. The task analysis data and observations during the mine visits also indicated that wherever a given unit operation was found, it had the same visual requirements, despite differences among mines or mining methods.

It has already been pointed out that visual discrimination of any sort is best done over a certain range of adaptation luminance and contrast conditions. This optimum range is bounded on the lower end by conditions too dark or contrasts too low for adequate performance, and on the upper end by excessive amounts of light and contrast that result in discomfort and disability glare. Optimum conditions should be provided in underground mining. Provision of enough light is only a part of the problem. The manner in which the light is controlled (by proper placement, luminaire design, and shielding) and the quality of the light (spectral energy content, steadiness) are equally important, yet frequently neglected in current mining practice. Eventual recommendations for mine lighting must take full account of these considerations.

Additionally, it is important to note that increased luminance for various unit operations may be achieved in several ways; these include: (1) increase the number of luminaires, (2) increase the lumen output of the present luminaires, or (3) rearrange the configurations of luminaires used in the various unit operations. Our data indicate that, in general, the amount of luminance may not be the most critical factor but the distribution of light at working sites may be more important. That is, it appears that luminance may need to be increased in certain parts of the working area and not in others. Thus, it is entirely possible that in many cases a simple rearrangement or redistribution of light sources in the working environment may be the most effective method to solve some of the illumination problems which have been noted with regard to the working environment.

Although the minimum luminance requirements for the unit operations found in the metal and nonmetal industry are yet to be determined, it is unlikely that a single standard will prove appropriate. But, if not a single standard, how are the standards to be defined? The current research indicated that the factor most influencing the amount of luminance needed is the task or unit operation being performed. Many different unit operations take place at a given type of work site, and are each likely to have differing luminance needs. If those differences are small, a standard based on the type of work site or perhaps even a single standard would work. The answer to the above question will only be found with the determination of the minimal luminance requirements for each task of unit operation.

DETERMINATION OF MINIMAL LUMINANCE REQUIREMENTS

At this point, we have (1) identified the illumination characteristics of underground work locations, (2) determined the gonioreflectance of sampled surfaces in metal and nonmetal mines, (3) identified the underground work activities, and (4) identified the accident and employment distributions for underground mining. However, several more pieces of data are required to determine the minimal luminance levels required for safe mining. These data are obtained through several steps including, (1) identifying the critical visual tasks, (2) determining the task visibilities, and (3) integrating the findings with previous research and with the standards of the Illumination Engineering Society.

The results of the task analyses serves as a basis for selecting the specific visual tasks to be evaluated. The task analysis provided the following information about each unit operation:

(1) Frequency of occurrence in each mining method.

(2) Common errors and accidents associated with performance of the unit operation.

(3) Inherent hazards associated with the unit operation.

(4) Difficulty of performing the unit operation.

(5) Visual tasks involved in the performance of the unit operation.

Each job task involves several visual tasks. For example, the unit operation "slushing" involves such visual tasks as detecting frayed slusher cables and identifying rock bolts in the muck pile. It is neither feasible nor necessary to determine required luminances for all visual tasks of each and every unit operation. Rather, it is important to identify the visual tasks that are critical to the safe and efficient performance of the unit operation. Determination of the minimal luminance requirements of this subset of visual tasks will define the minimal luminance requirements of the associated unit operations.

Visual tasks will be selected that are performed frequently, or are infrequently performed but are critical. Errors and accidents associated with the visual task will be judged in terms of the contribution illumination might play in them. Visual task difficulty will also be considered. The critical visual tasks will be selected on the basis of the following criteria:

(1) Safety, i.e., the consequences of an error to the operator.

(2) Productivity, i.e., the consequences of an error to the efficient performance of the entire unit operation.

(3) Importance, i.e., the frequency of performance and time needed to perform the task.

(4) Prevalence, i.e., how often the unit operation associated with the task is performed across the industry.

Once the subset of critial visual tasks is defined, it will be possible to identify those tasks common to various subsets of unit operations. It is anticipated that some critical visual tasks may be unique to a single unit operation.

Two things are necessary for adequate visibility of a task in the mining environment: (1) sufficient luminance and (2) adequate contrast between objects and their background. Illumination, or illuminance as it is sometimes termed, is the intensity of light per unit area incident on a surface. However, for the purposes of determining the visibility of a task, illuminance is not enough. Thus, task visibility is specified in terms of luminance which is the intensity of light per unit area reaching the eye. Luminance determines the adaptation level of the viewer. As adaptation level increases, when all other parameters are constant, visual performance improves.

Illuminance interacts with the reflectances of the materials to determine the luminance perceived by the individual. For example, fixed illuminance of a coal face, where the reflectance is low, would be expected to produce lower luminances than the same illuminance of a salt face where the reflectance is higher. Because adaptation level is determined by luminance, adaptation level, and thus visual performance, would be higher in the salt mine than in the coal mine (if all other factors are the same).

For an object to be visible, it must have, in addition to an adequate luminance level, sufficient light/dark contrast with its background. The illumination methods now used in many mines may severely degrade contrast because of glare and scattered light from particles in the air (aerosols, hydrosols), from deposits on the miner's eyeglasses, and from particles within the eyes.

Glare or scattered light, whether created within the eye or outside the eye, adds a veiling luminance to the retinal image of the mining task. This veiling luminance washes out scene contrast just as turning on the room lights washes out a projected color slide. In many mine environments, the loss of contrast due to glare and scattering may constitute a greater problem than the absolute level of luminance itself.

As an example, assume that in a given mining task the target object has a luminance of .058 cd/m^2 (.2 fL), and the background has a luminance of .029 cd/m^2 (.1 fL), a light/dark contrast ratio of 2:1 (100% contrast). Assume also that a veiling luminance of .029 cd/m^2 (.1 fL) is created by ambient light scattered from particles in the air and from deposits on the miner's glasses. This .029 cd/m^2 (.1 fL) is added to the .058 cd/m^2 (.2 fL) of the target object: .058 + .292 = .350 cd/m^2 (.2 + 1.0 = 1.2) and to the .029 cd/m^2 (.1 fL) of the background: .029 + .292 = .321 cd/m^2 (.1 + 1.0 = 1.1), thus washing out the previous 2:1 contrast ratio to only 12:11 or 1.09:1 (about 9% contrast). If, in addition to producing veiling luminance, the scattering particles also cut the transmission of target object luminance by half, the resulting contrast ratio will be further degraded to 11:10.5, or 1.05:1 (about 5% contrast). This is close to the threshold limit for contrast visibility in the operational mining environment.

In a task environment that produces a significant amount of glare and scattering of light, an increase in the absolute level of task luminance is often accompanied by a proportional increase in the amount of veiling luminance, with no net gain in visibility. This is well illustrated by the effect of using high beam headlights in fog: any gain in highway illumination is negated by an increase in veiling luminance which washes out the roadway scene.

A careful analysis of each task environment is necessary to determine in what ways any increase in illumination may be negated by increased glare and scattering, and how the ratio of target luminance to veiling luminance can be increased to improve visual contrast.

These two factors of luminance and contrast interact; at lower luminance levels more contrast is required to see a given object or task, and the illumination methods now used in many mines may severely degrade contrast because of glare and scattering of light from particles in the air (aerosols, hydrosols), from deposits on the miner's eyeglasses, and from particles within the eyes.

Finally, to make sound recommendations regarding minimal luminance ranges needed for safe and efficient job performance in underground metal and nonmetal mines, it is essential that all relevant factors in the visibility of tasks be considered. This means integrating the data obtained in the current research with those data in the coal mine illumination study (Hitchcock, 1973) and with the standards of the Illuminating Engineers Society (Kaufman, 1981). From these integrated data will be drawn the recommendations for minimal luminance requirements. Such recommendations must also give full weight to factors known to limit task visibility, including:

(1) Disability glare.
(2) Scattering due to aerosols and hydrosols.
(3) Transient adaptation effects ("temporary blindness").
(4) Losses due to protective eyewear.
(5) Vision requirements of the mine population ("the aged eye").

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